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Sams et al.

(10) **Patent No.: US 9,095,790 B2**
(45) **Date of Patent: Aug. 4, 2015**

(54) **HIGH VELOCITY ELECTROSTATIC COALESCING OIL/WATER SEPARATOR**

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(73) Assignee: **Cameron International Corporation**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 491 days.

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(65) **Prior Publication Data**

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(51) **Int. Cl.**

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B01D 17/04	(2006.01)
B03C 11/00	(2006.01)
C10G 33/02	(2006.01)

(52) **U.S. Cl.**

CPC ***B01D 17/06*** (2013.01); ***B01D 17/045*** (2013.01); ***B03C 11/00*** (2013.01); ***C10G 33/02*** (2013.01); *B03C 2201/02* (2013.01)

(58) **Field of Classification Search**

CPC B01D 17/06; B03C 11/00

USPC 204/573

See application file for complete search history.

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(Continued)

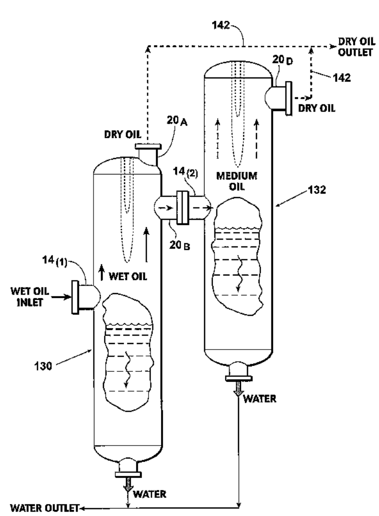
Primary Examiner — Bryan D. Ripa

(74) *Attorney, Agent, or Firm* — Gable Gotwals

(57) **ABSTRACT**

An apparatus and method for separating water from an oil-and-water mixture includes at least two elongated separator vessels oriented at an incline and connected to one another so that an upwardly flowing oil predominant fluid passes from the first separator vessel to the second separator vessel where further electrostatic separation of water from the oil predominant fluid occurs. Each vessel has an electrode at its upper end preferably connected to a different voltage source. The inlet to each vessel is located relative to the electrode to provide an up flow or a down flow vessel. Additionally, the first vessel may be at a different elevation than the second vessel. An additional vessel may be included with output from the first vessel bypassing the additional vessel, the second vessel, or both. Baffles may be added in the water collection portion of each vessel to reduce turbulence and settling distance.

9 Claims, 23 Drawing Sheets



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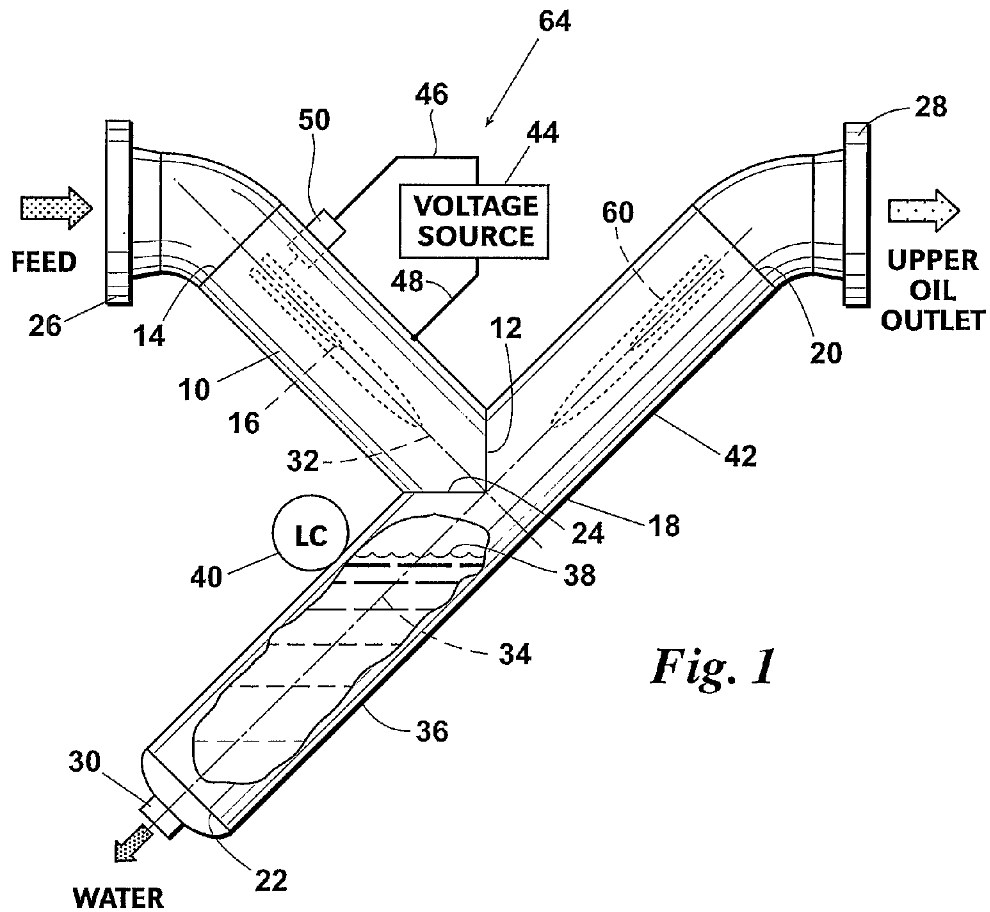

64
46
44
50
28
VOLTAGE SOURCE
60
FEED
UPPER OIL OUTLET
48
26
14
12
20
10
16
42
32
24
18
LC
40
38
34
36
30
22
WATER

Fig. 1

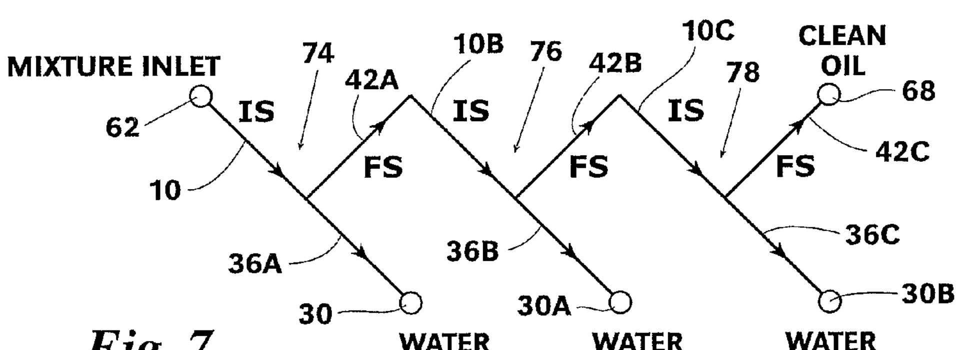

MIXTURE INLET
74
10B
76
10C
CLEAN OIL
42A
42B
78
68
62
IS
IS
IS
FS
FS
FS
42C
10
36A
36B
36C
30
30A
30B
WATER
WATER
WATER

Fig. 7

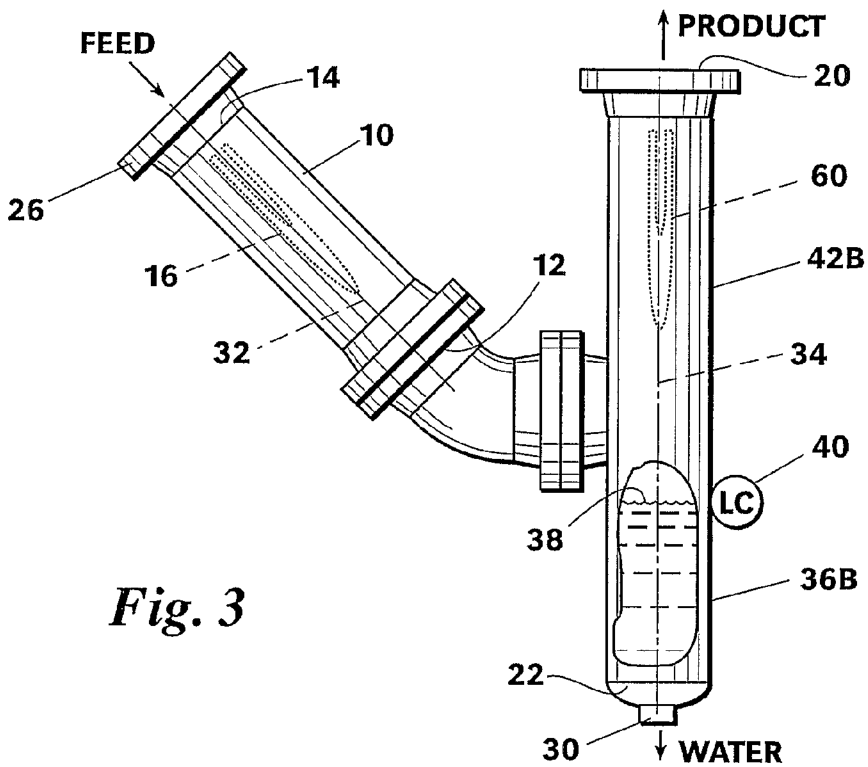

PRODUCT
FEED
14
20
10
60
26
42B
12
16
32
34
40
LC
38
36B
22
30
WATER

Fig. 3

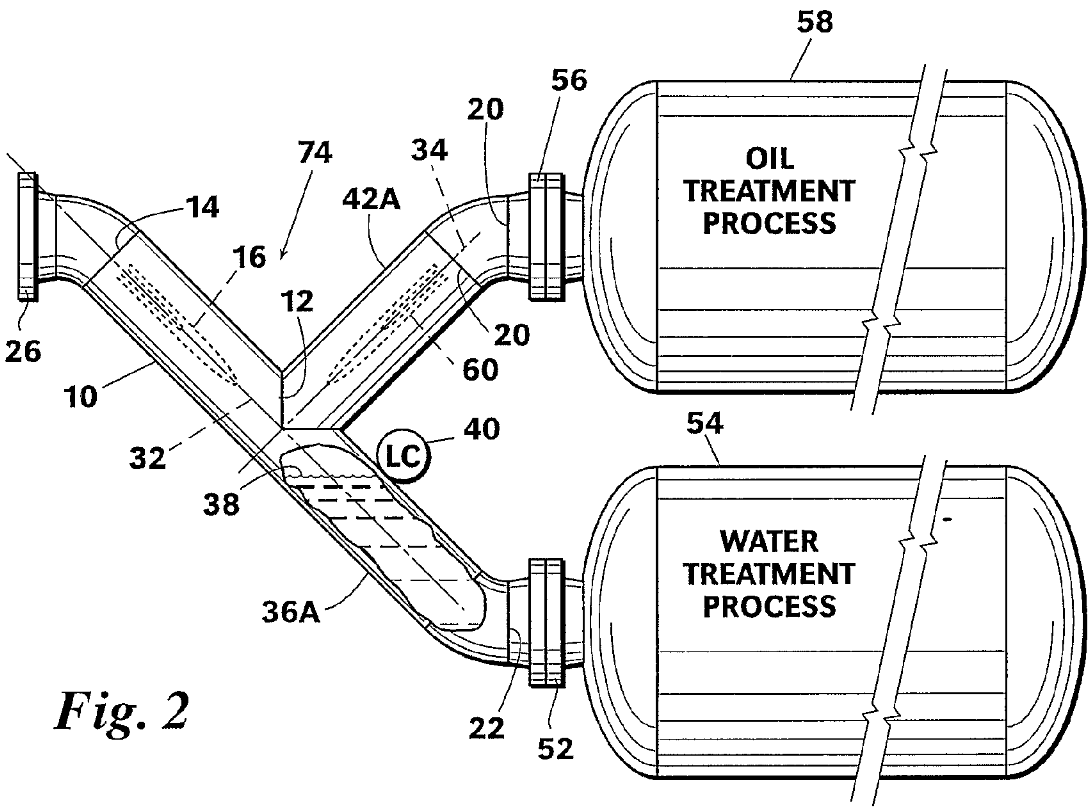

58
56
20
74
34
OIL
TREATMENT
PROCESS
42A
14
16
12
20
26
60
10
40
54
LC
32
38
WATER
TREATMENT
PROCESS
36A
22
52

Fig. 2

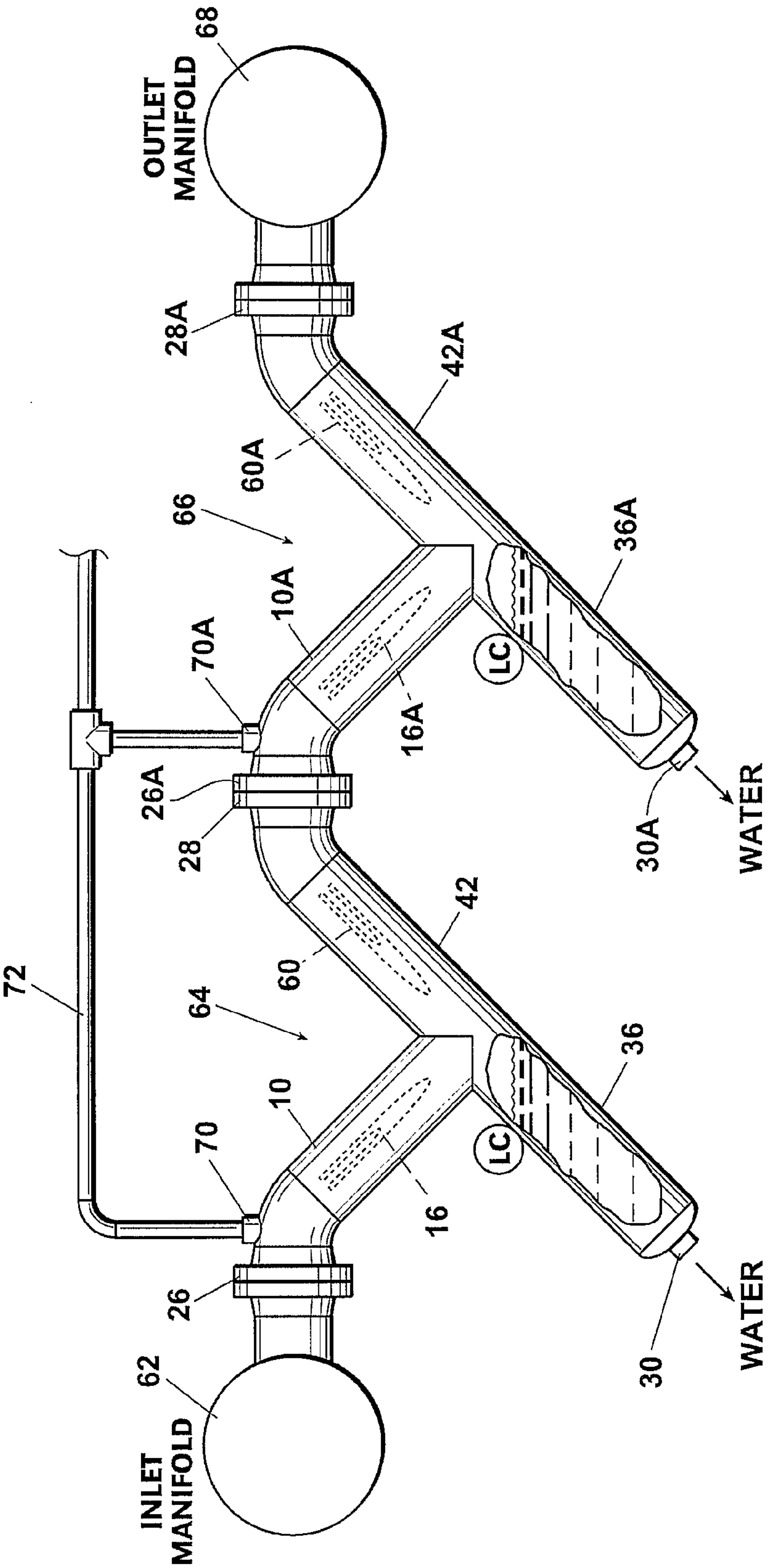
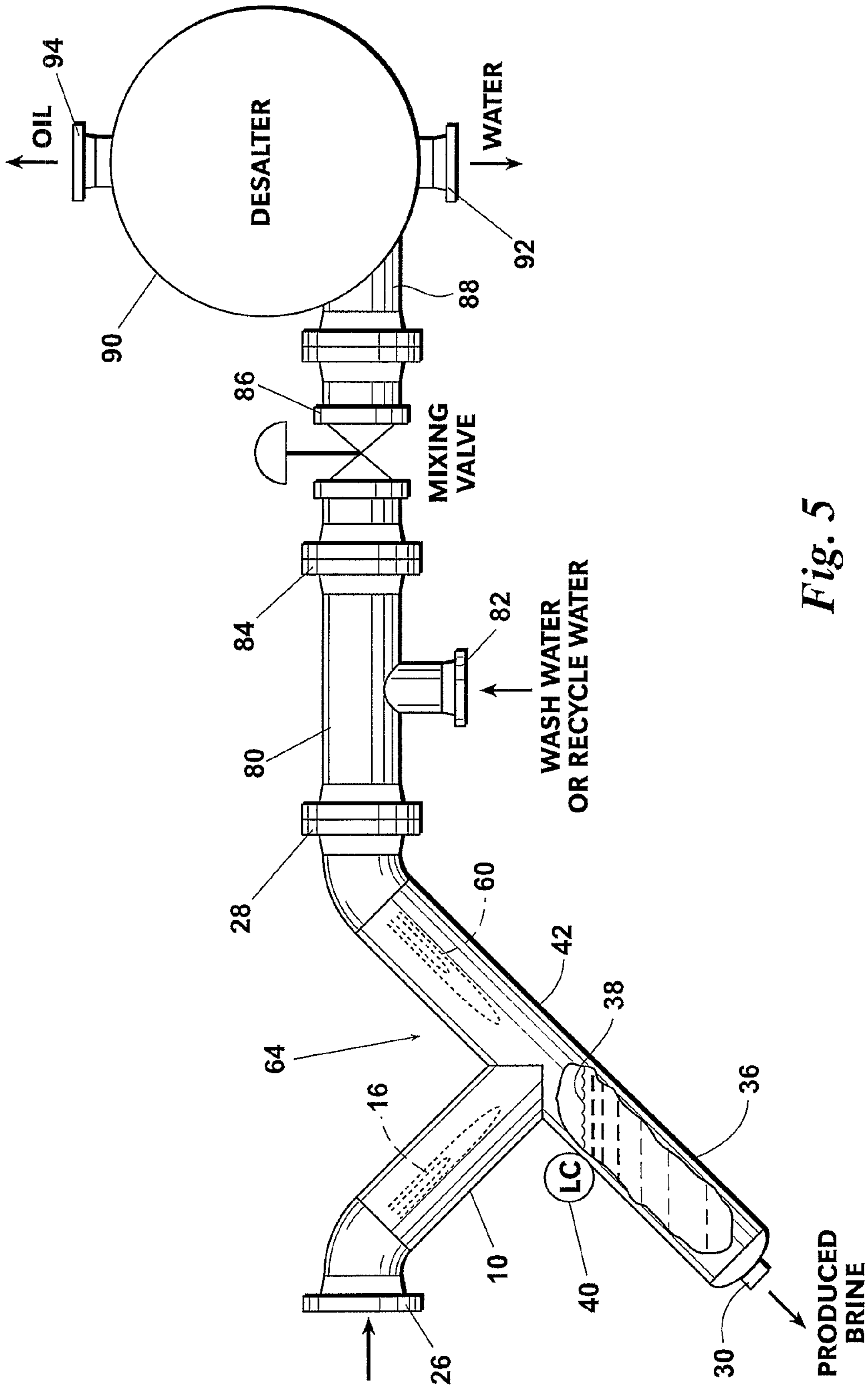

OUTLET MANIFOLD
68
28A
42A
60A
66
36A
10A
70A
LC
16A
26A
28
30A
WATER
42
72
60
64
36
10
70
LC
16
26
62
30
WATER
INLET MANIFOLD

Fig. 4



OIL
94
DESALTER
WATER
92
90
88
86
MIXING VALVE
84
82
WASH WATER OR RECYCLE WATER
80
28
60
42
64
38
36
16
LC
10
40
26
30
PRODUCED BRINE

Fig. 5

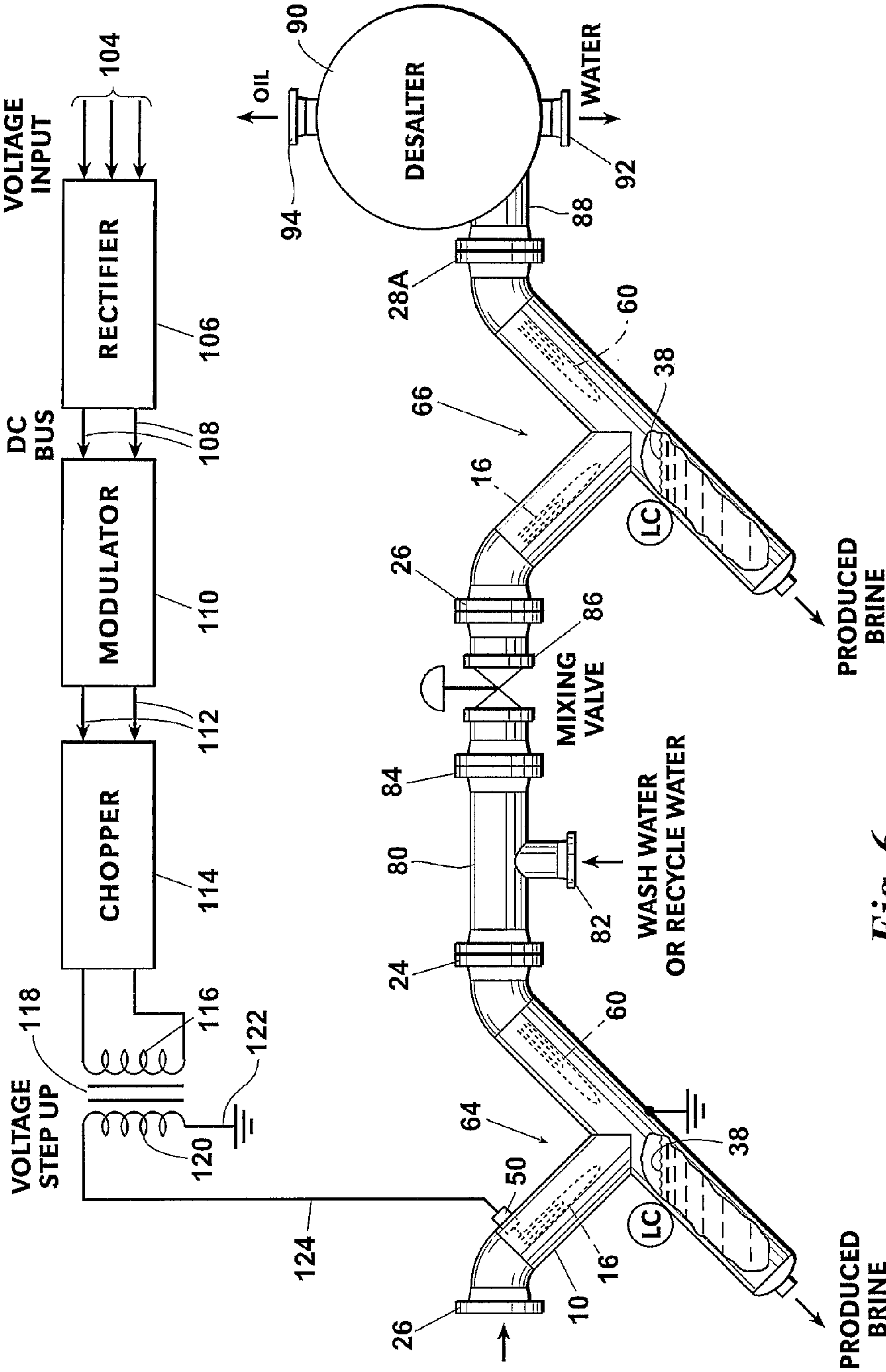

VOLTAGE INPUT
104
RECTIFIER
106
DC BUS
108
MODULATOR
110
112
CHOPPER
114
116
118
VOLTAGE STEP UP
120
122
124
DESALTER
90
OIL
94
WATER
92
88
28A
60
38
66
16
LC
PRODUCED BRINE
26
86
MIXING VALVE
84
80
WASH WATER OR RECYCLE WATER
82
24
64
50
10

Fig. 6

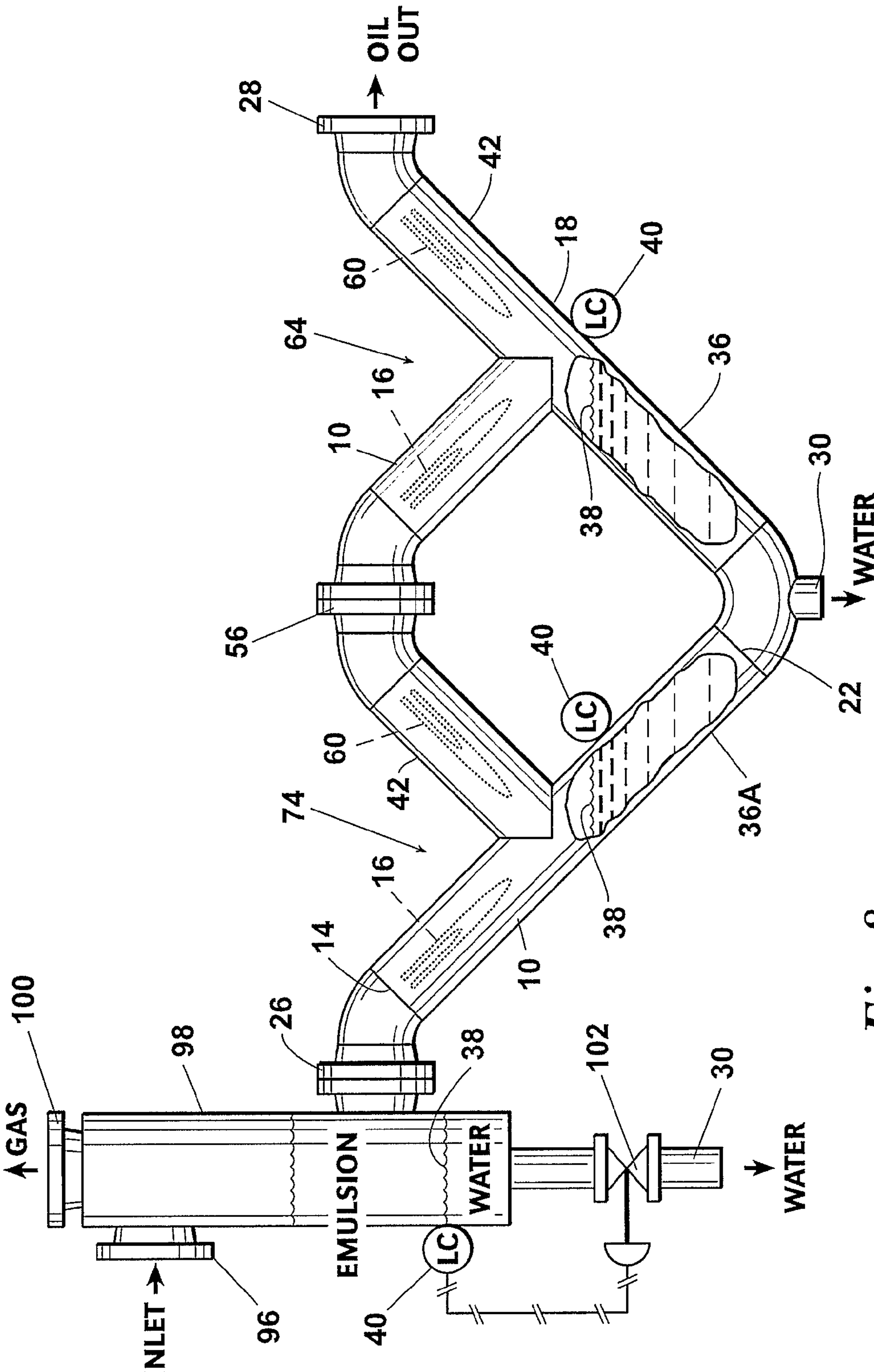

OIL OUT
28
42
18
40
LC
60
64
16
10
36
30
WATER
38
56
40
LC
22
60
42
74
36A
16
14
38
10
100
GAS
98
26
38
EMULSION
WATER
102
30
WATER
LC
INLET
96
40

Fig. 8

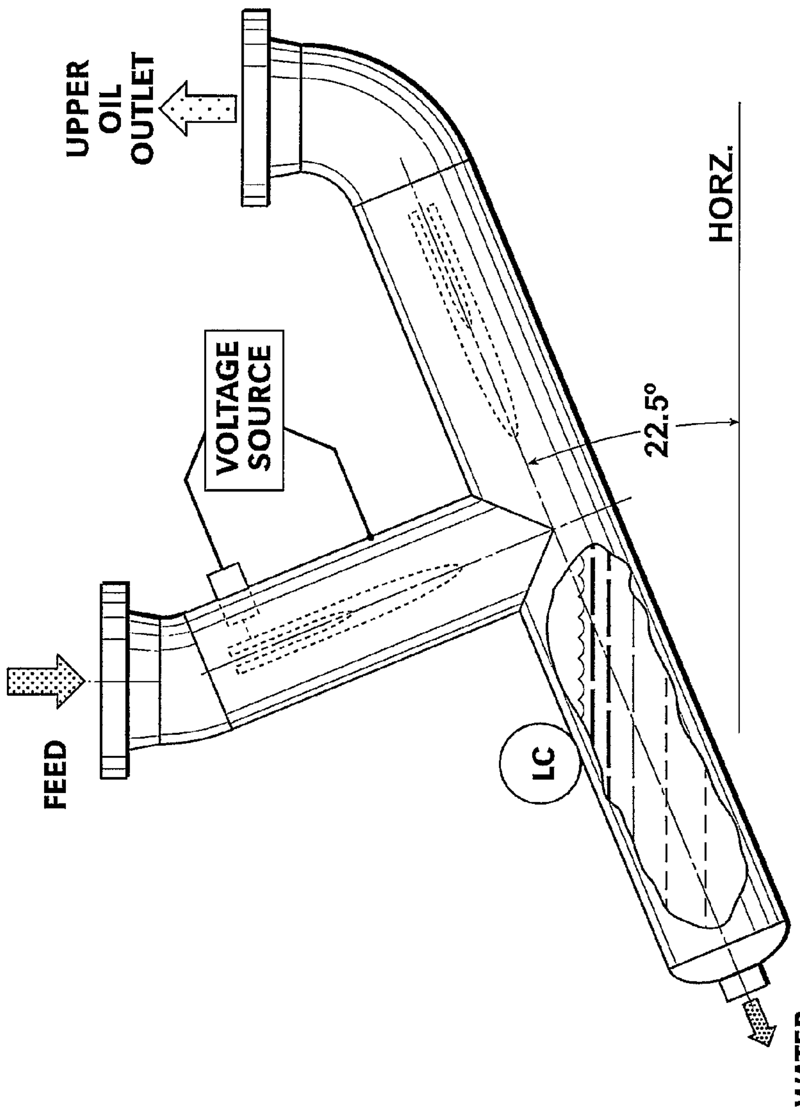


Fig. 9

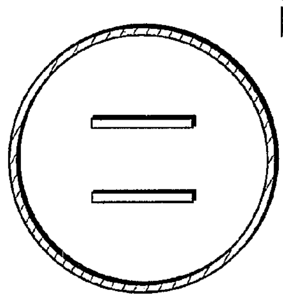


Fig. 10

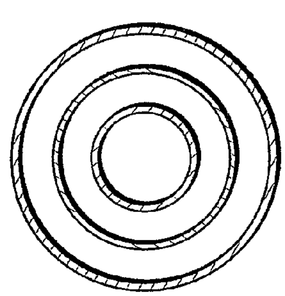


Fig. 11

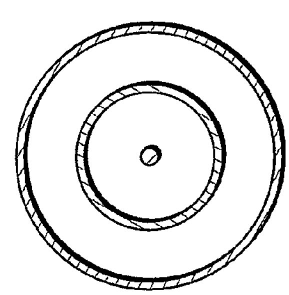


Fig. 12

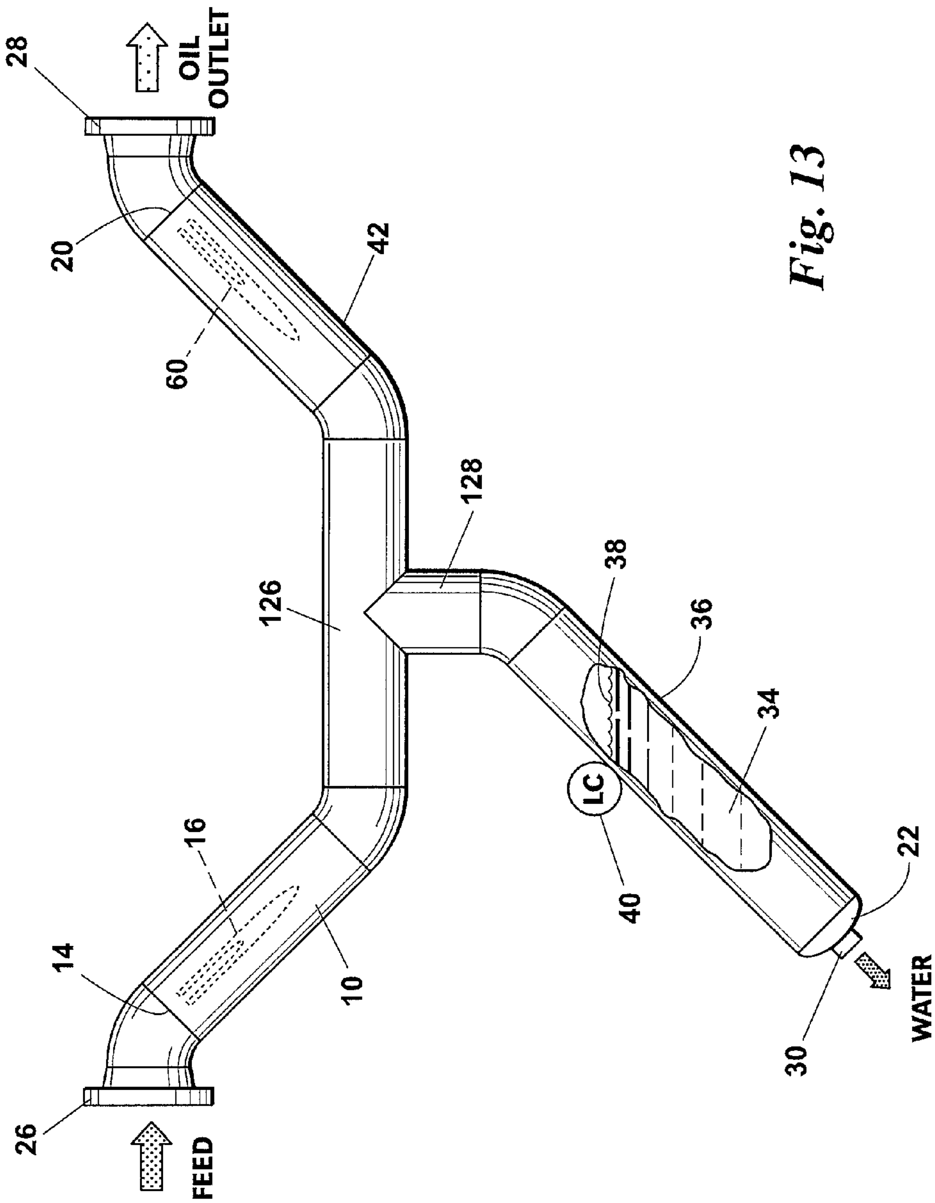

28
OIL OUTLET
20
42
60
128
126
38
36
34
LC
40
16
14
10
22
30
WATER
26
FEED

Fig. 13

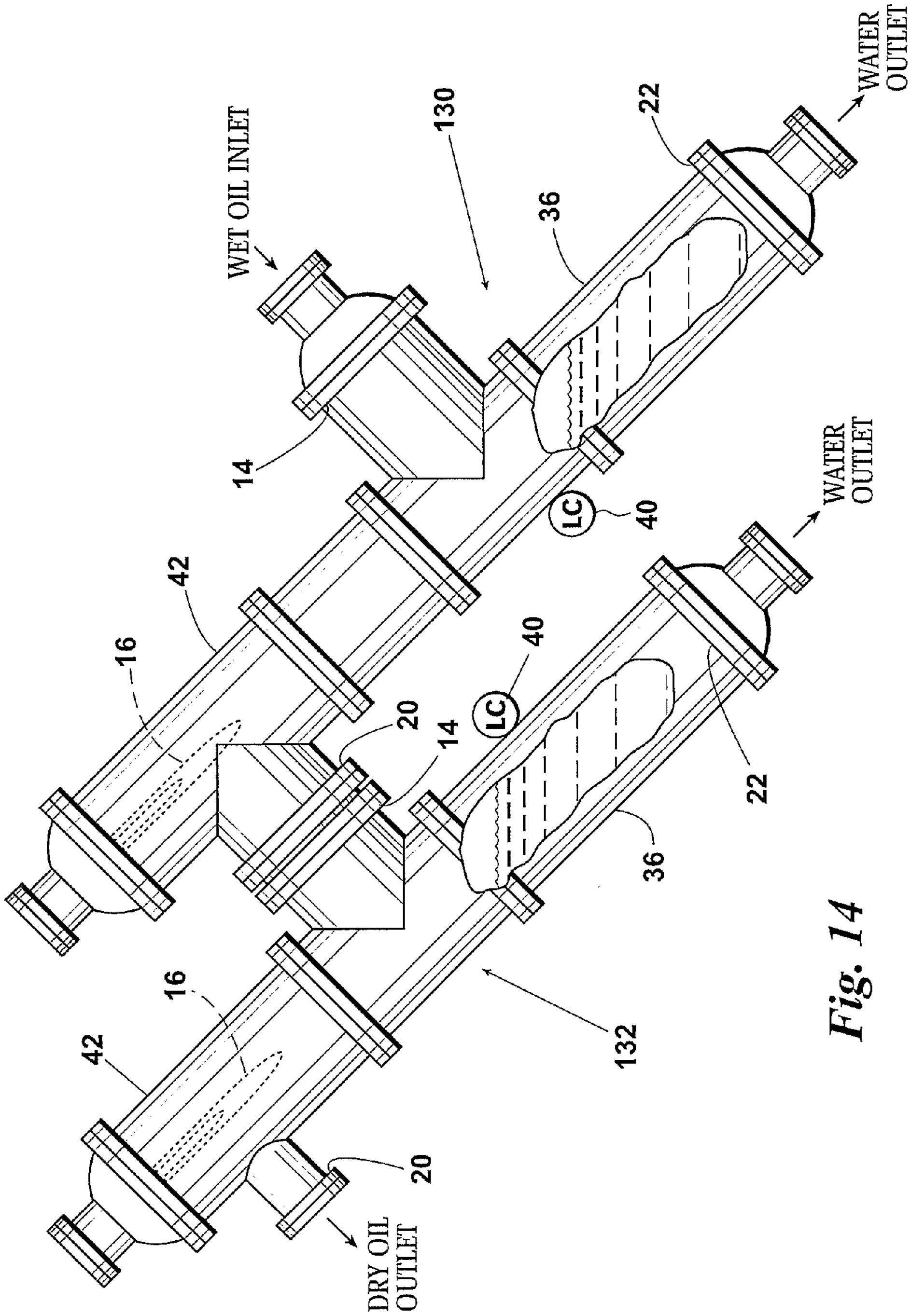

WET OIL INLET
130
WATER OUTLET
22
36
14
LC
40
WATER OUTLET
42
16
40
LC
20
14
22
36
16
42
132
20
DRY OIL OUTLET

Fig. 14

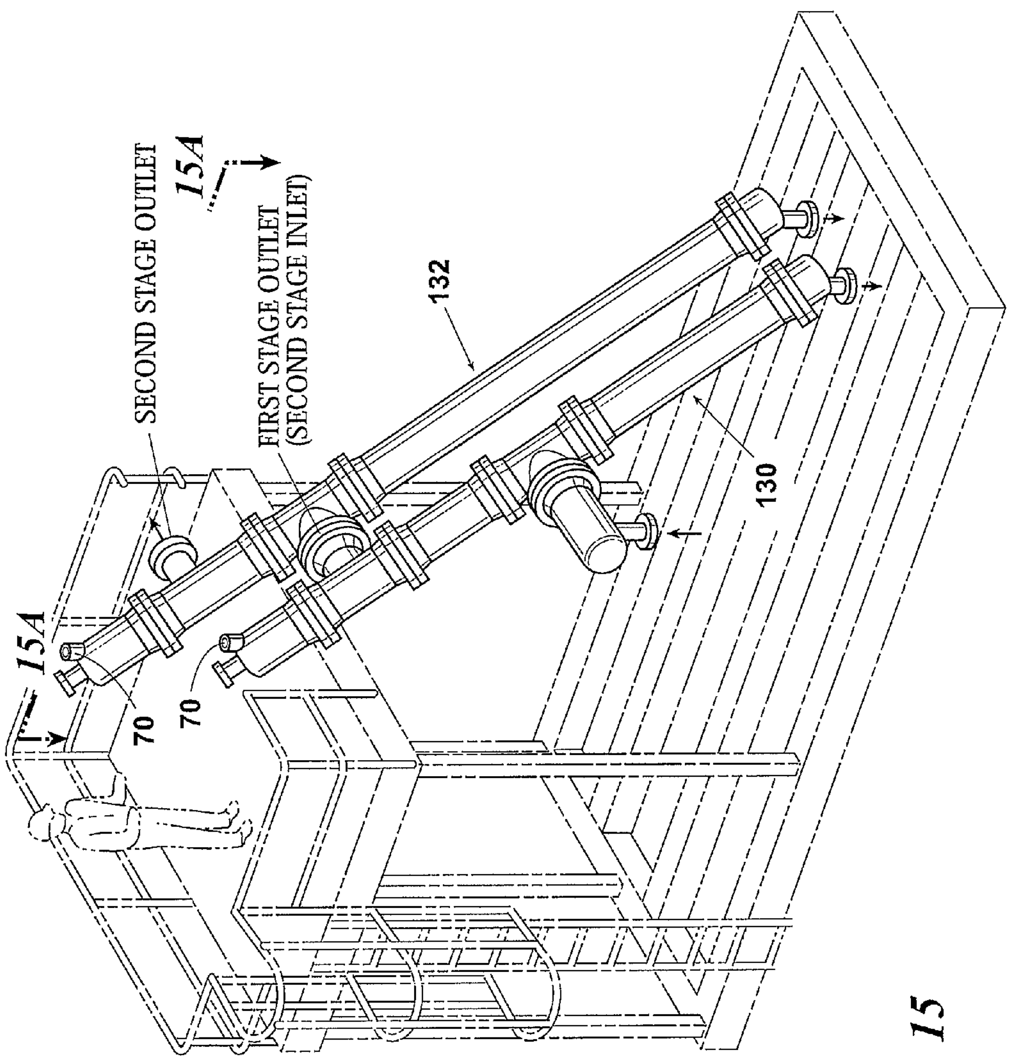

SECOND STAGE OUTLET
15A
FIRST STAGE OUTLET
(SECOND STAGE INLET)
132
130
15A
70
70

Fig. 15

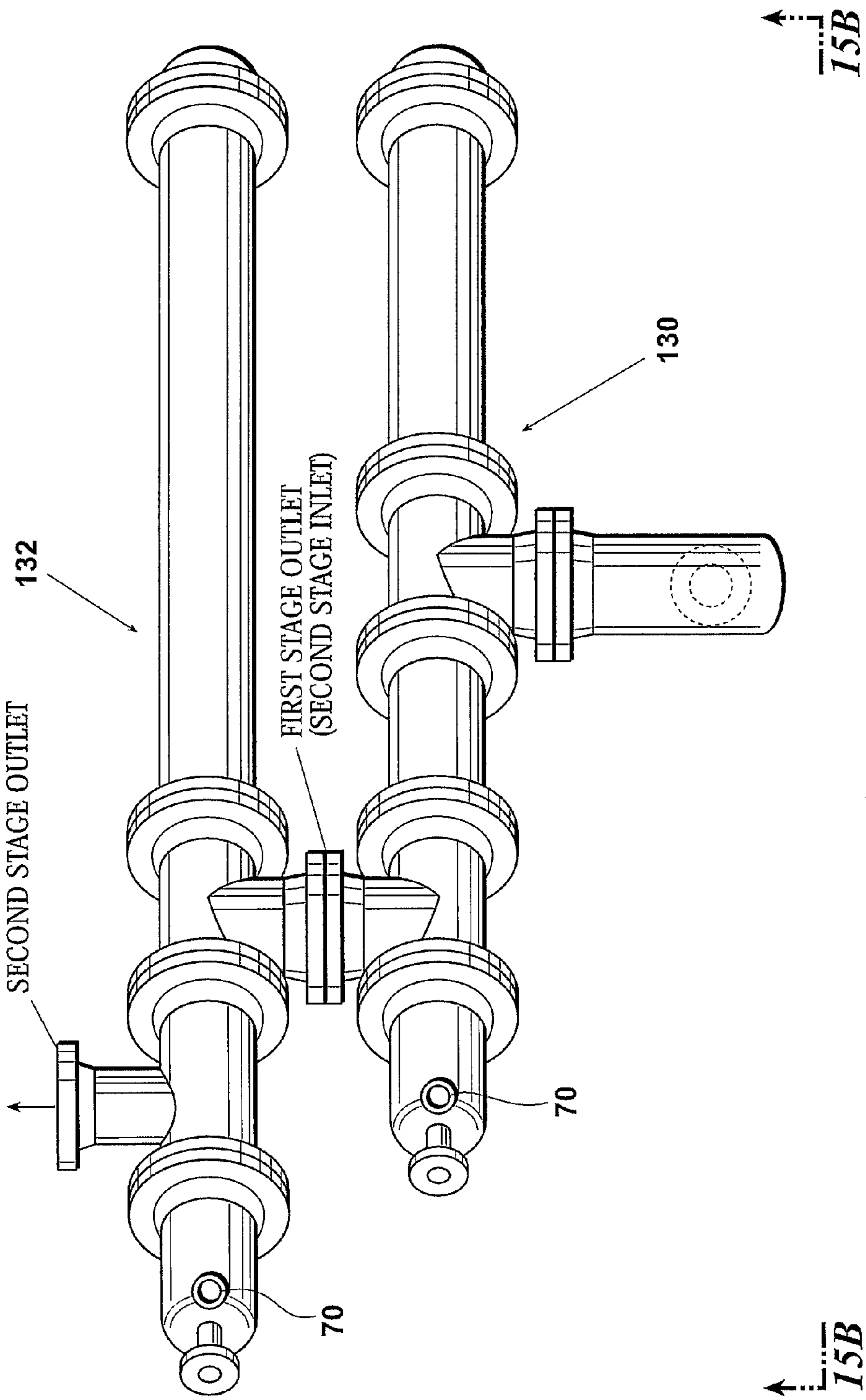

15B
132
130
SECOND STAGE OUTLET
FIRST STAGE OUTLET
(SECOND STAGE INLET)
70
70
15B

Fig. 15A

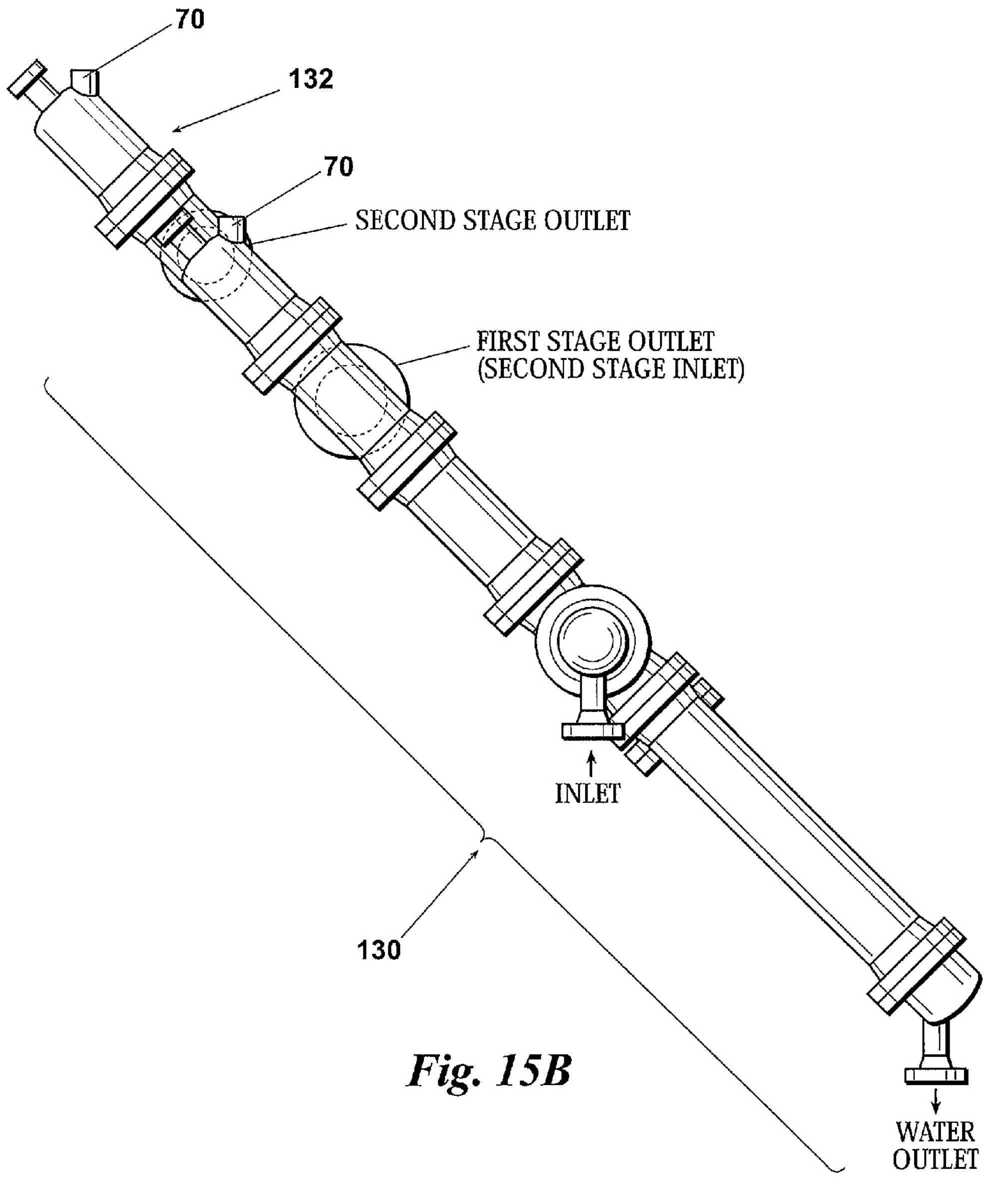

70
132
70
SECOND STAGE OUTLET
FIRST STAGE OUTLET
(SECOND STAGE INLET)
INLET
130
WATER
OUTLET

Fig. 15B

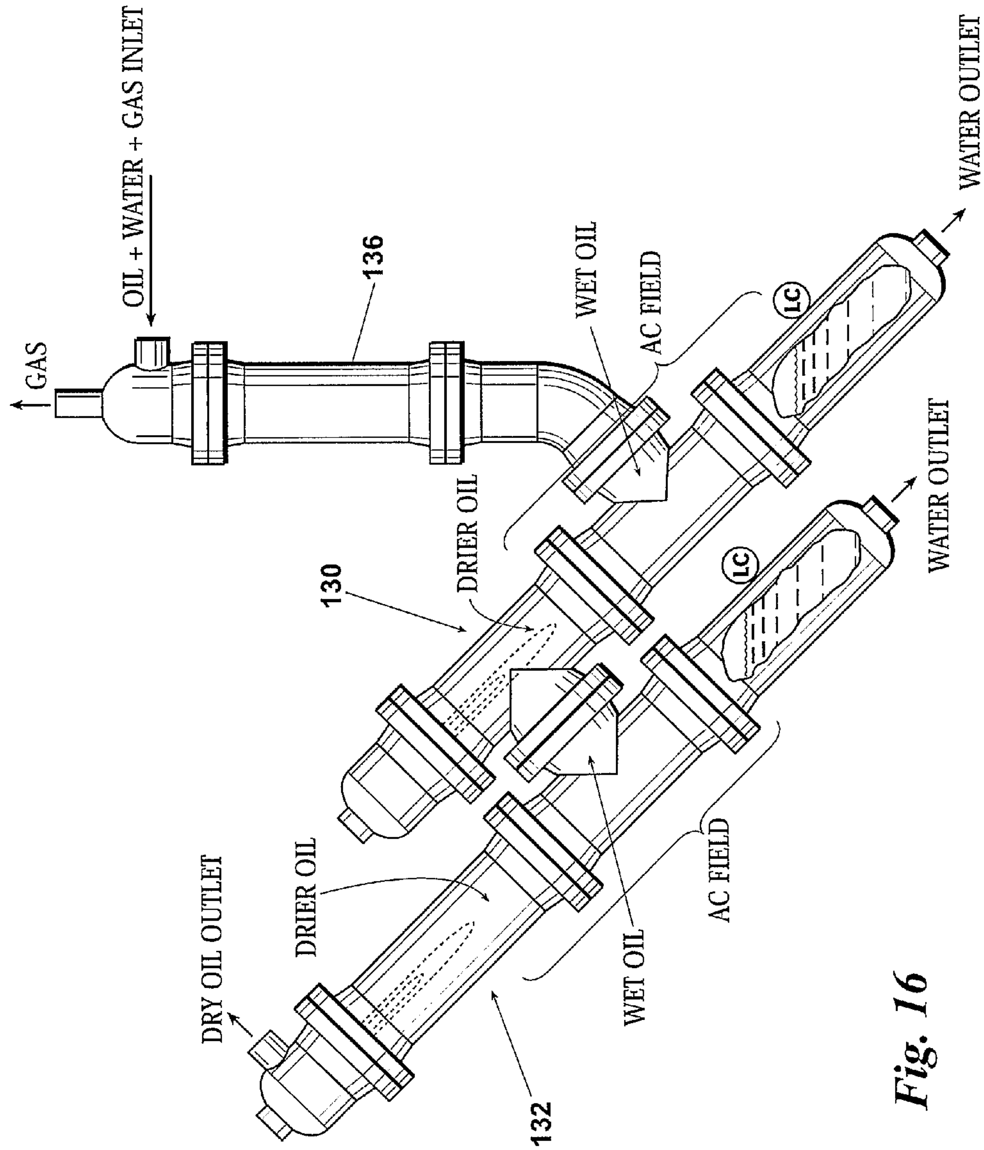

GAS
OIL + WATER + GAS INLET
136
WET OIL
AC FIELD
LC
WATER OUTLET
DRIER OIL
130
LC
WATER OUTLET
DRY OIL OUTLET
DRIER OIL
AC FIELD
WET OIL
132

Fig. 16

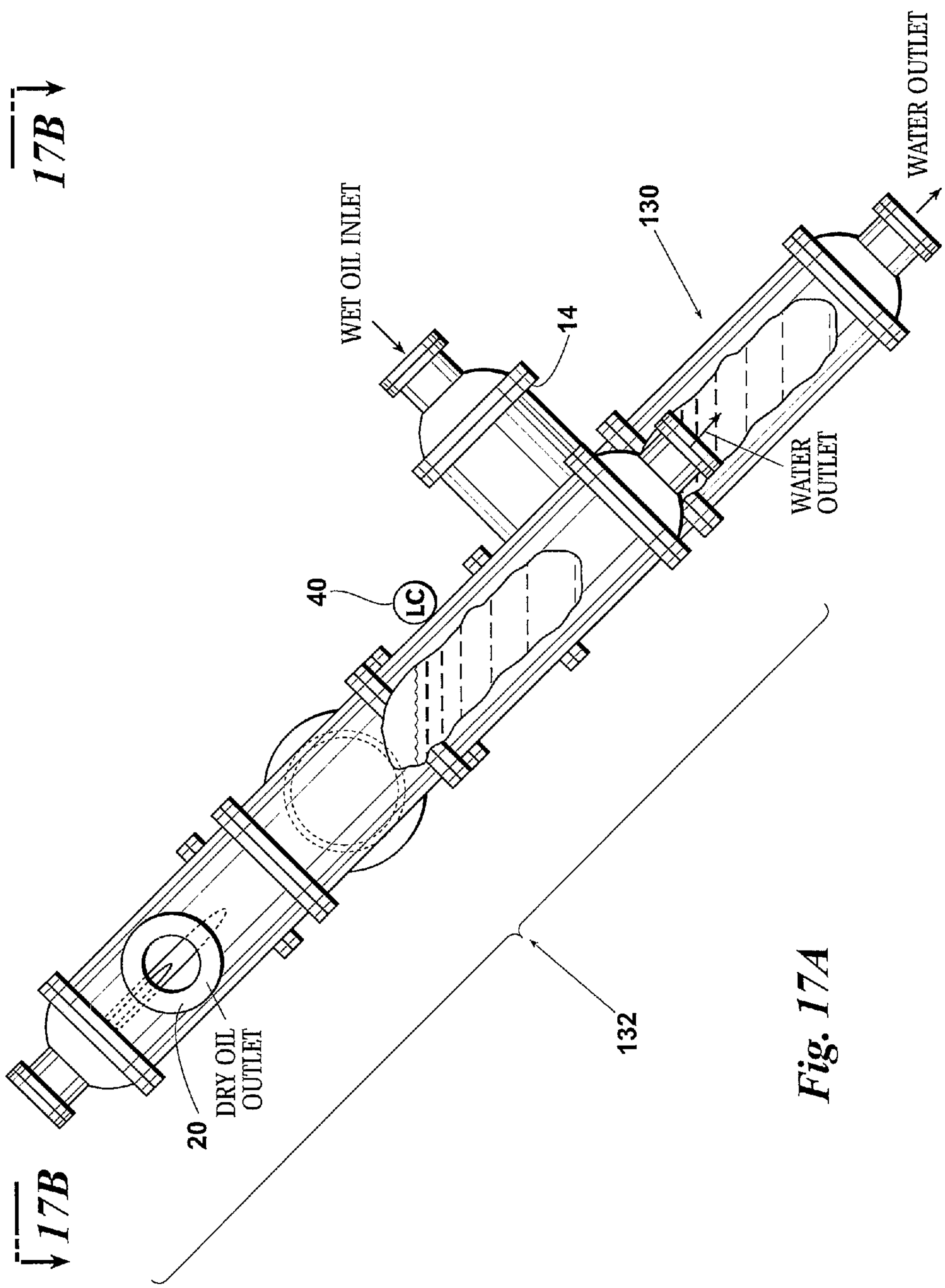

17B
WET OIL INLET
WATER OUTLET
130
14
WATER OUTLET
40
LC
20
DRY OIL OUTLET
132
17B

Fig. 17A

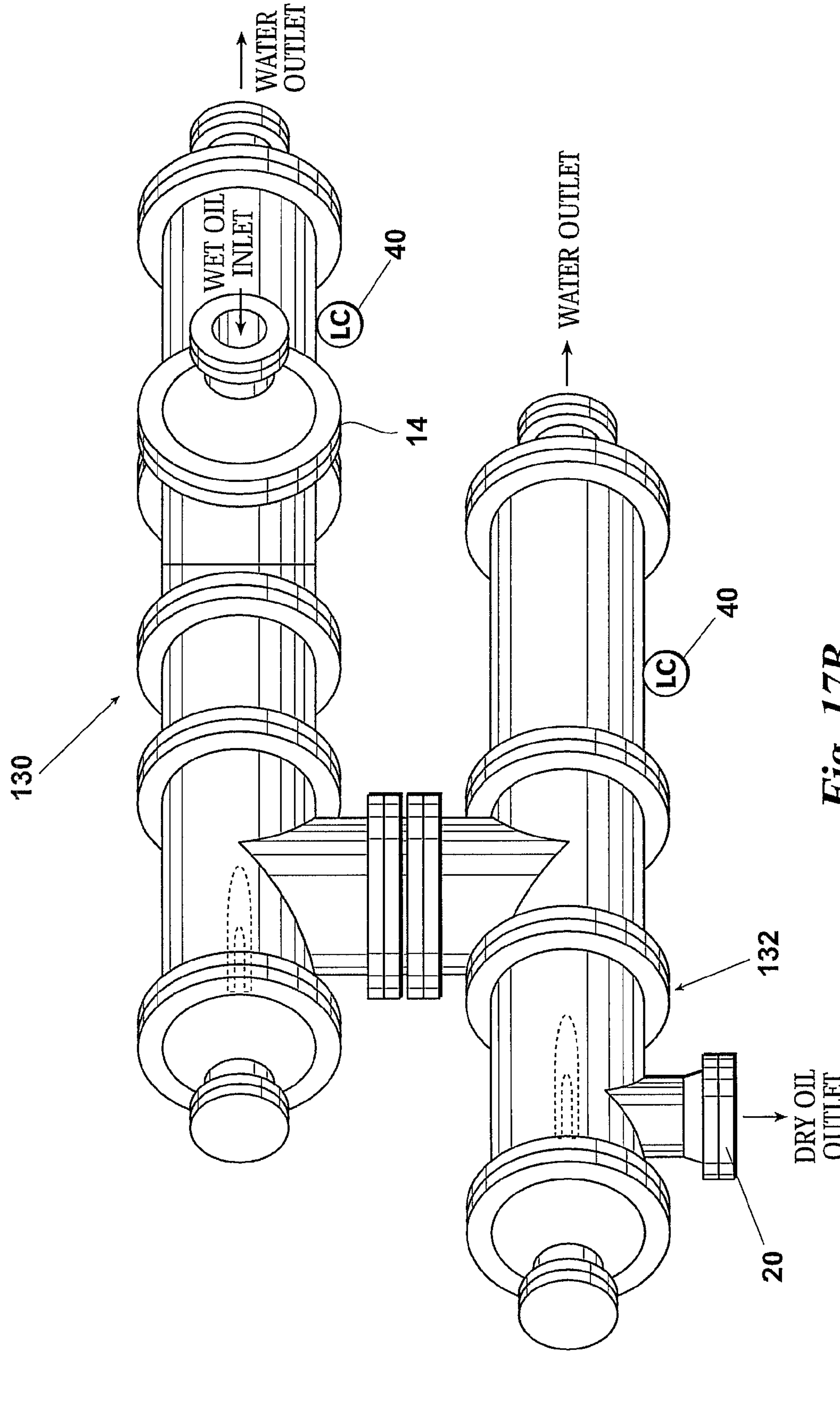

WATER OUTLET
WET OIL INLET
LC
40
14
WATER OUTLET
LC
40
130
132
DRY OIL OUTLET
20

Fig. 17B

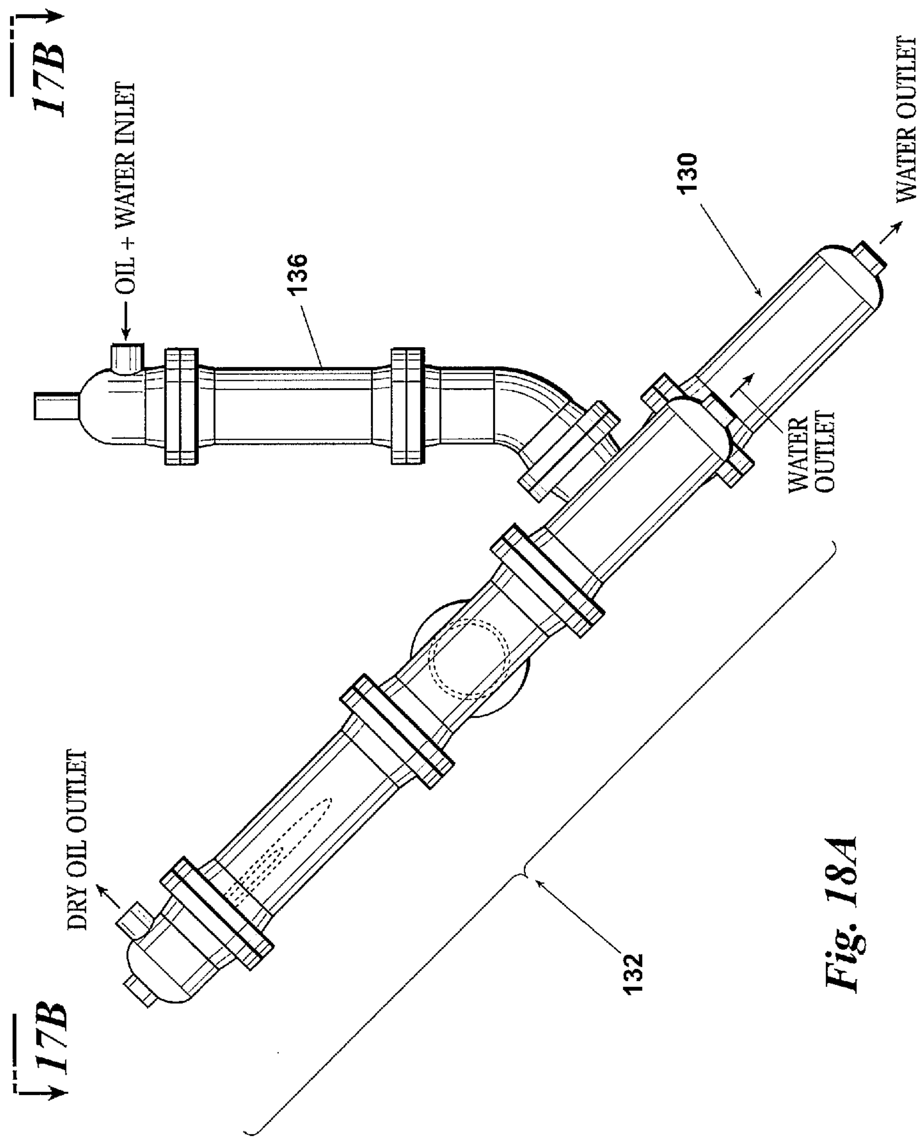

17B
OIL + WATER INLET
136
130
WATER OUTLET
WATER OUTLET
DRY OIL OUTLET
132
17B

Fig. 18A

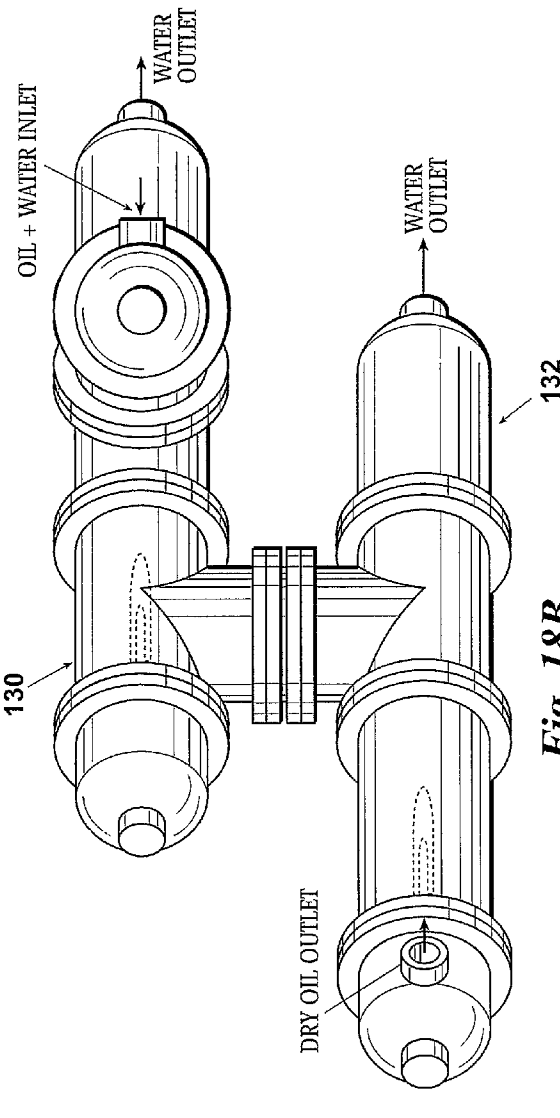


Fig. 18B

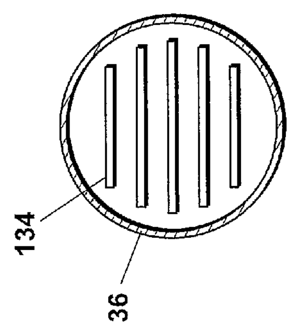


Fig. 19

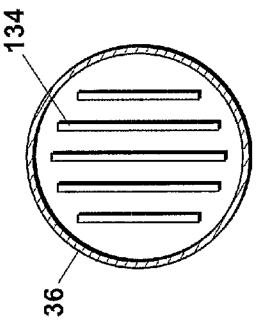


Fig. 20

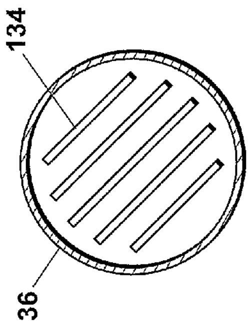


Fig. 21

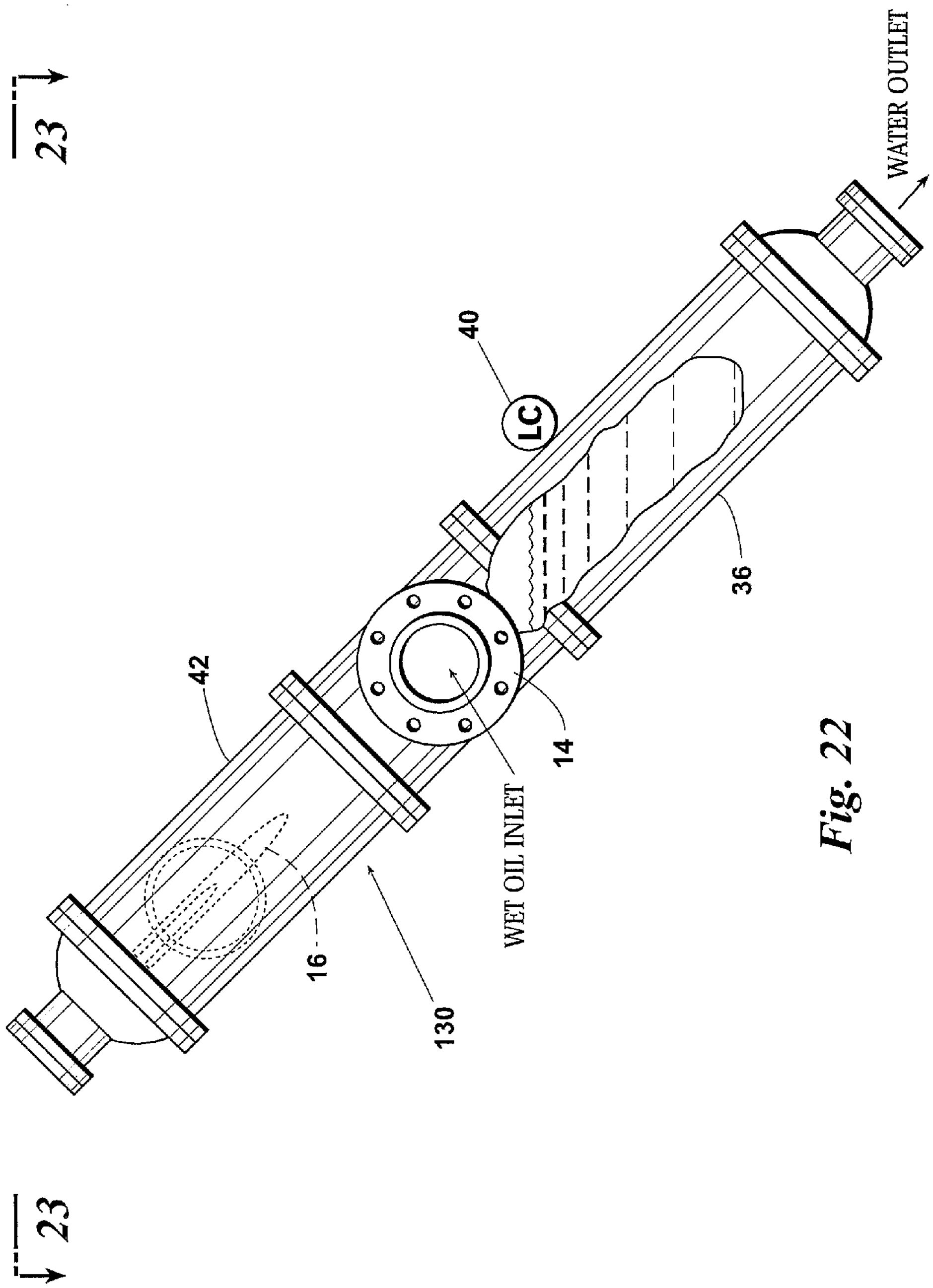


Fig. 22

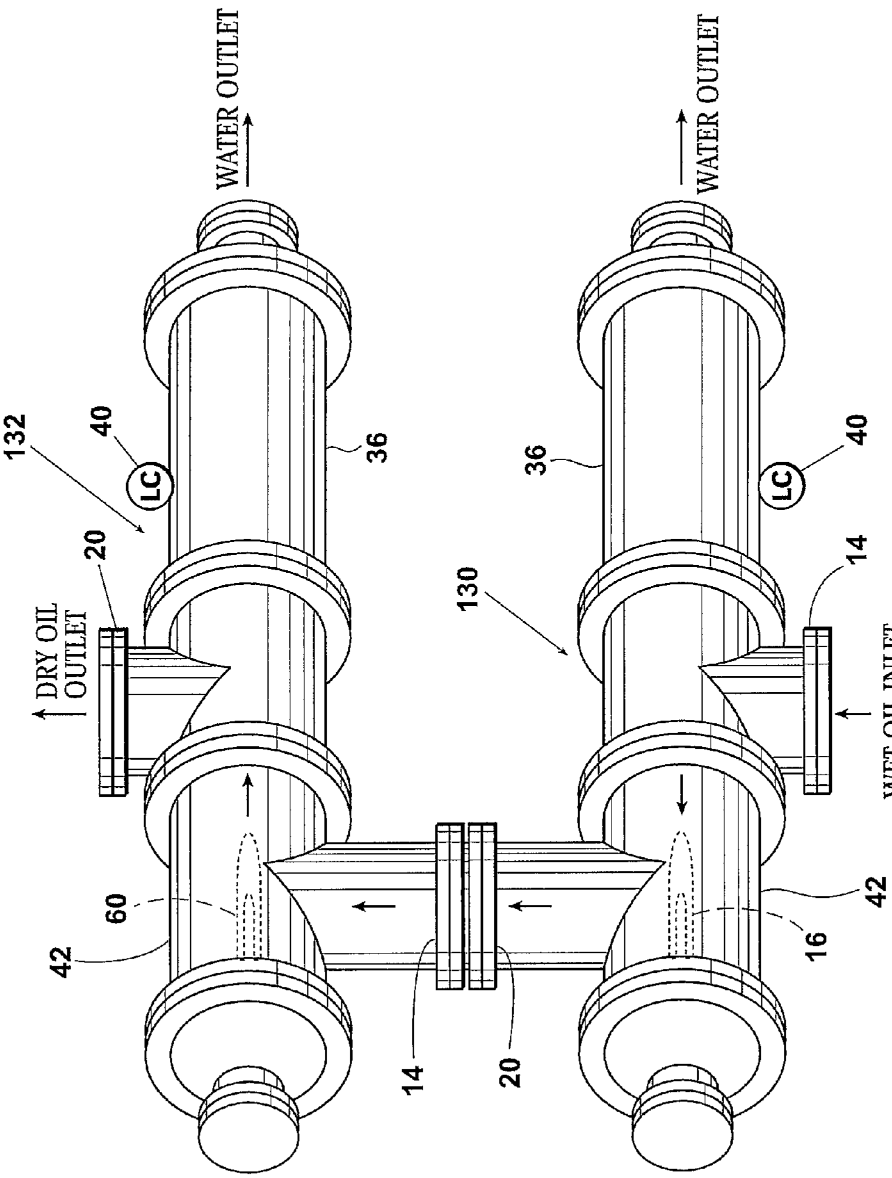

WATER OUTLET
WATER OUTLET
132
40
LC
36
36
40
LC
20
DRY OIL OUTLET
130
14
WET OIL INLET
60
42
42
16
14
20

Fig. 23

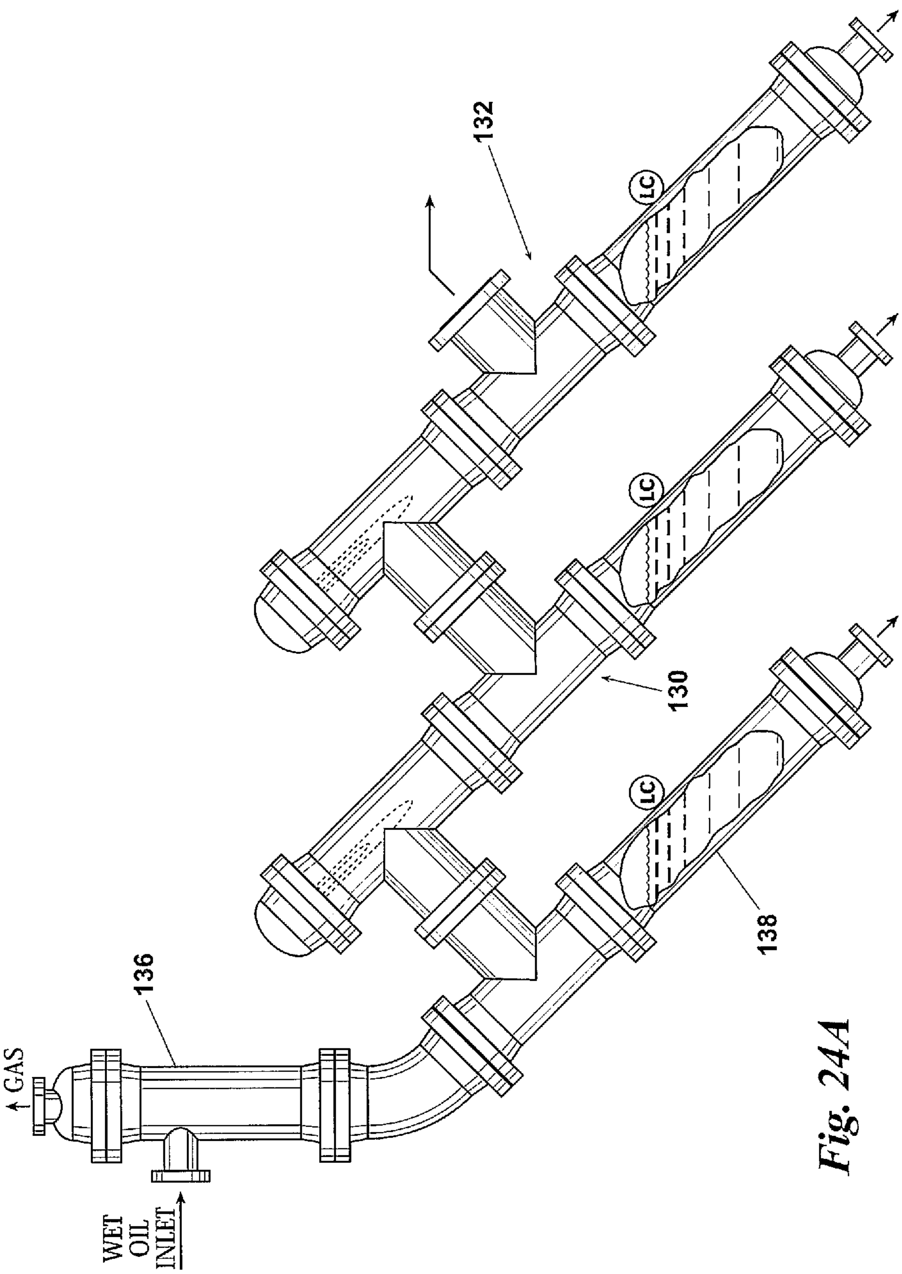


Fig. 24A

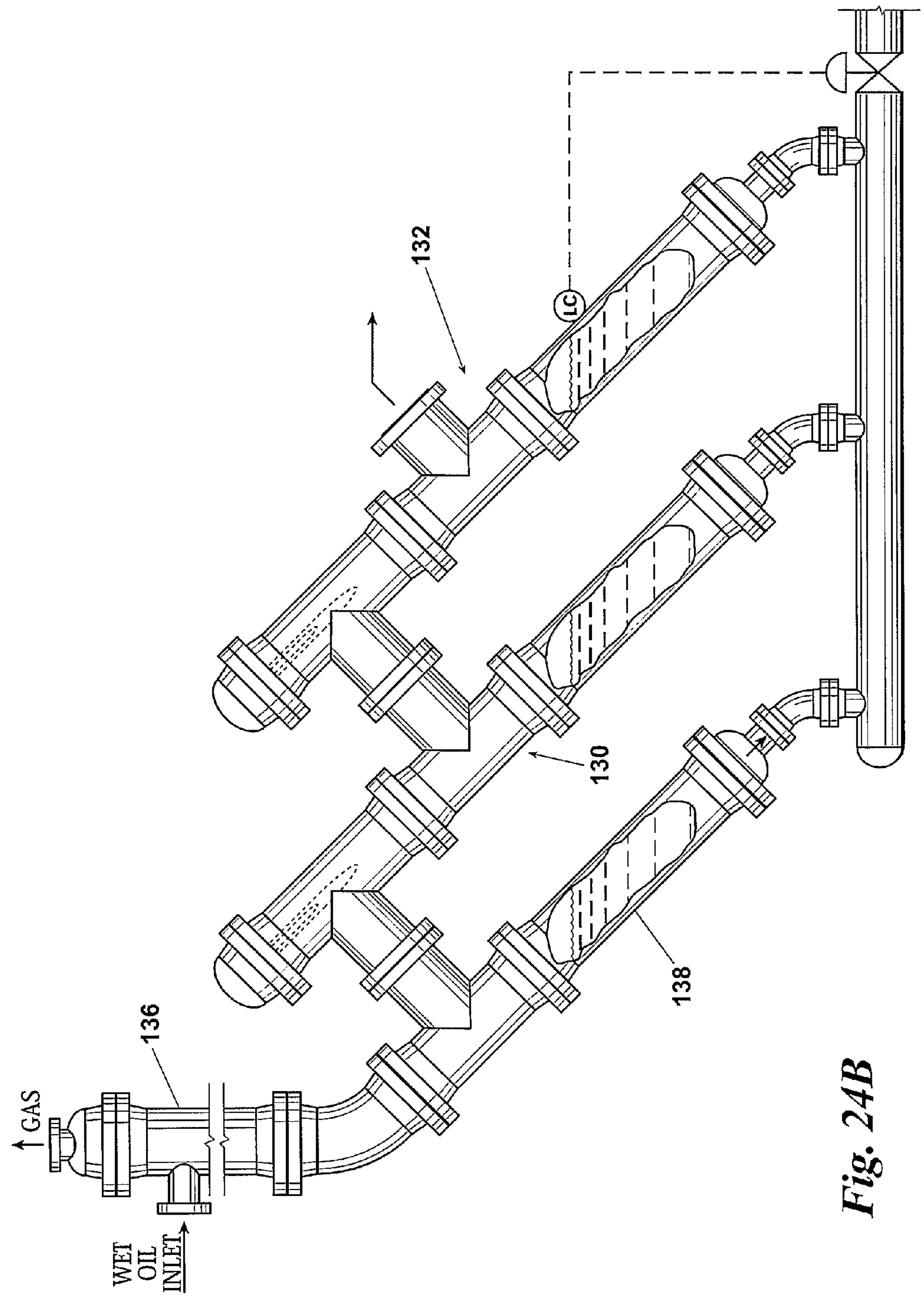


Fig. 24B

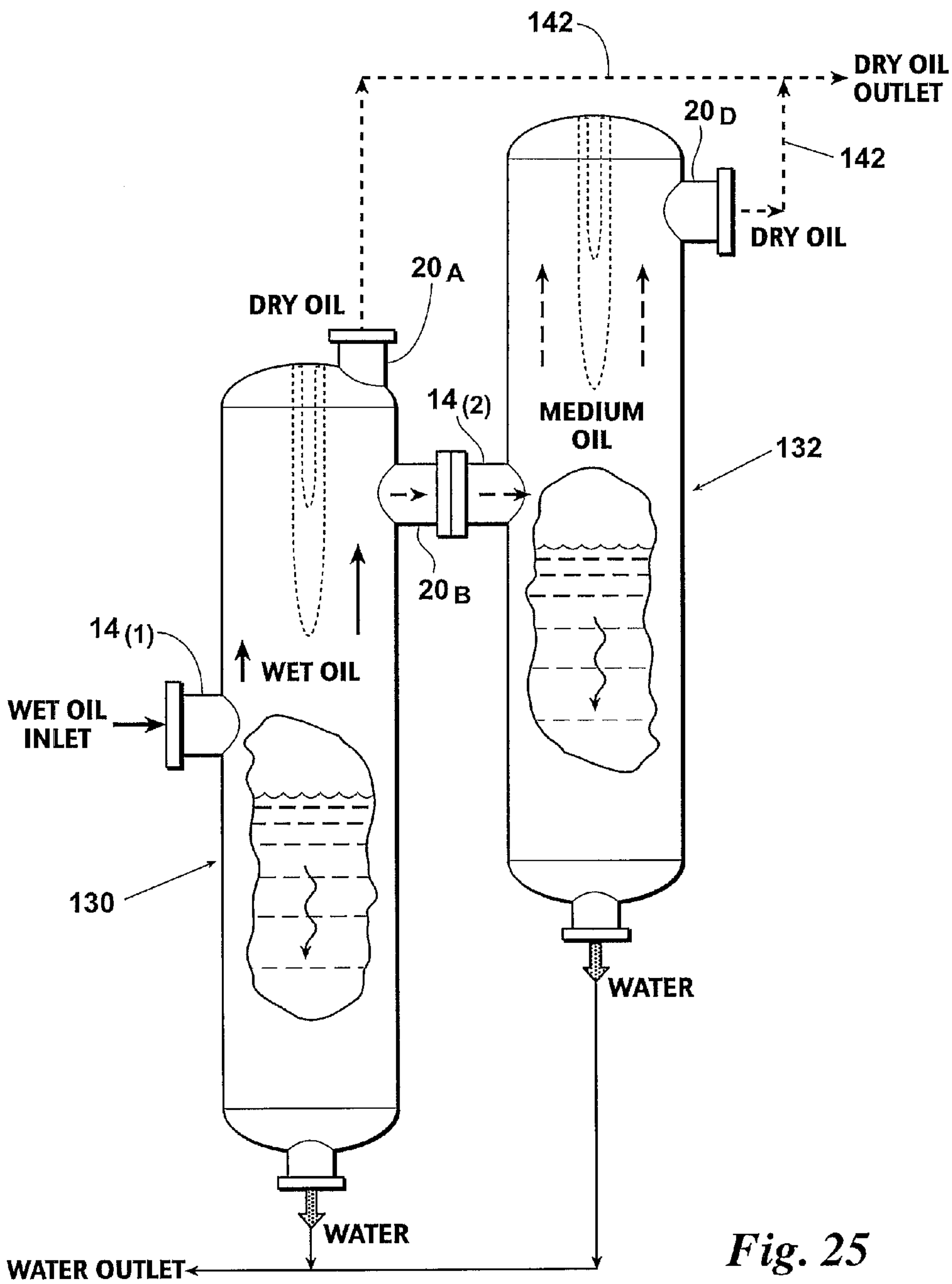

142
DRY OIL
OUTLET
20 D
142
DRY OIL
20 A
DRY OIL
14 (2)
MEDIUM
OIL
132
20 B
14 (1)
WET OIL
WET OIL
INLET
130
WATER
WATER
WATER OUTLET

Fig. 25

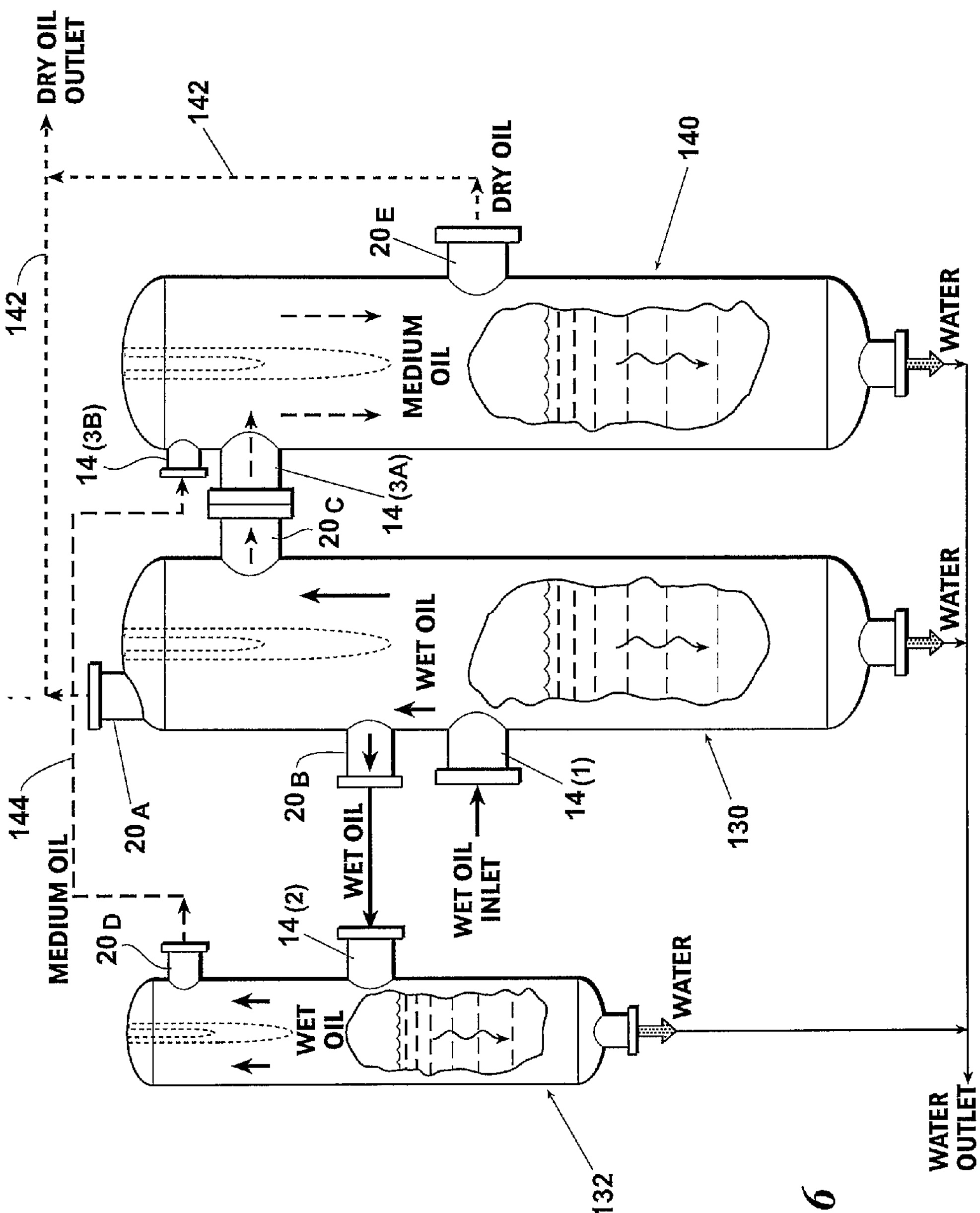

DRY OIL OUTLET
142
142
DRY OIL
140
20E
MEDIUM OIL
14 (3B)
14 (3A)
20C
WET OIL
WATER
WATER
144
MEDIUM OIL
20A
20B
WET OIL
14 (1)
WET OIL INLET
130
14 (2)
20D
WET OIL
WATER
132
WATER OUTLET

Fig. 26

HIGH VELOCITY ELECTROSTATIC COALESCING OIL/WATER SEPARATOR

REFERENCE TO PENDING APPLICATIONS

This application is not based upon any pending domestic or international patent applications.

FIELD OF THE INVENTION

This invention is in the field of electrostatic coalescence of immiscible components of a mixture, and is particularly related to the separation of water from a water-and-oil mixture.

BACKGROUND OF THE INVENTION

One of the world's most useful sources of energy is crude oil, derived from subterranean formations. When crude oil arrives at the earth's surface it is typically in the form of a water-and-oil mixture. That is, crude oil invariably has associated water that must be separated before the oil component can be efficiently refined into useful commercially acceptable products.

A common technique for improving the effectiveness of oil/water separation is by use of coalescence—that is a technique of joining together smaller into larger water droplets that are more readily separated from the mixture. As water droplet size increases, the dynamics of gravitational separation improve. One method of augmenting coalescence of water droplets is by subjecting the mixture to an electric field. Oil, being a non-polar fluid, acts as a dielectric and water droplets, being polar, when subjected to an electric field are coalesced. Coalescence is usually practiced by establishing an electric field between electrodes and passing an oil-in-water mixture through the electric field. Since water is slightly polar, water droplets become polarized by the electric field. Polarized droplets are attracted to each other and move into and coalescence with each other. Larger droplets tend to gravitate downwardly within the mixture and the oil, having portions of the water removed therefrom, tend to gravitate upwardly within the mixture.

Much work has been done in the area of electrostatic coalescence of a mixture to augment separation of oil and water components. Background information relating to the inventive subject matter contained herein can be obtained from the following United States patents:

Pat. No.	Inventor	Title
1,116,299	Laird et al.	Process of treating petroleum emulsions
1,276,387	McKibben	Method of separating associated liquids
1,838,931	Fisher	Apparatus for converting commercial frequency circuits into high frequency circuits
2,120,932	Dillon	High frequency induction dehydrator
2,849,395	Wintermute	Method and apparatus for electrical separation of emulsions
3,772,180	Prestridge	Electric treater
3,839,176	McCoy	Method and apparatus for removing contaminants from liquids
3,847,775	Prestridge	Process for electrical coalescing of water
4,126,537	Prestridge	Method and apparatus for separation of fluids with an electric field
4,161,439	Warren et al.	Apparatus for application of electrostatic fields to mixing and separating fluids
4,200,516	Pope	Electrostatic coalescing system
4,204,934	Warren et al.	Process for application of electrostatic fields to mixing and separating fluids
4,224,124	Pope	Electrostatic coalescing system
4,283,290	Davies	Purification utilizing liquid membrane with electrostatic coalescence
4,290,882	Dempsey	Electrostatic separation of impurities phase from liquid-liquid extraction
4,308,127	Prestridge	Separation of emulsions with electric field
4,400,253	Prestridge	Voltage control system for electrostatic oil treater
4,415,426	Hsu et al.	Electrodes for electrical coalescence of liquid emulsions
4,417,971	Ferrin et al.	Circuit for maintaining the strength of an electrostatic field generated in a fluid mixture of varying dielectric strength
4,469,582	Sublette et al.	Electrically enhanced inclined plate separator
4,479,161	Henrich et al.	Switching type driver circuit for fuel injector
4,581,119	Rajani et al.	Apparatus for separating a dispersed liquid phase from a continuous liquid phase by electrostatic coalescence
4,581,120	Sublette	Method and apparatus for separating oilfield emulsions
4,601,834	Bailes et al.	Settling of liquid dispersions
4,606,801	Prestridge et al.	Electrostatic mixer/separator
4,702,815	Prestridge et al.	Distributed charge composition electrodes and desalting system
4,747,921	Bailes	Liquid-liquid contacting
4,767,515	Scott et al.	Surface area generation and droplet size control in solvent extraction systems utilizing high intensity electric fields
4,804,453	Sublette et al.	Resolution of emulsions with multiple electric fields
5,147,045	Chi et al.	Particulate separations by electrostatic coalescence
5,411,651	Yamaguchi et al.	Method for electrostatic liquid/liquid contactor
5,421,972	Hickey et al.	Process and apparatus for removing soluble contaminants from hydrocarbon streams
5,464,522	MacEdmondson	Electrostatic oil emulsion treating method and apparatus
5,543,027	Yamaguchi et al.	Apparatus for electrostatic liquid/liquid contactor
5,565,078	Sams et al.	Apparatus for augmenting the coalescence of water in a water-in-oil emulsion
5,575,896	Sams et al.	Method and apparatus for oil/water separation using a dual electrode centrifugal coalescer
5,643,431	Sams et al.	Method for augmenting the coalescence of water in a water-in-oil emulsion

-continued

Pat. No.	Inventor	Title
5,824,203	Remo	Method and means for changing characteristics of substances
6,010,634	Sams et al.	System and method for separating mingled heavier and lighter components of a liquid stream
6,113,765	Wagner et al.	Methods for enhanced resolution of hydrocarbon continuous emulsions or dispersions with conductivity modifiers
6,860,979	Sams	Dual Frequency Electrostatic Coalescence

BRIEF SUMMARY OF THE INVENTION

This invention provides a method and apparatus for separating water from a water-and-oil mixture. The invention is particularly useful for separating water from crude oil. A great deal of the energy consumed on the earth today is derived from crude oil that is found in subterranean deposits and brought to the earth's surface by wells. When the crude oil reaches the earth's surface it invariably is in the form of a water-and-oil mixture. That is, crude oil is usually found associated with water. In order to successfully and economically transport, refine and make use of crude oil, one of the first requirements after the crude oil is brought to the earth's surface is to separate out and properly dispose of the water content. Methods and various systems for accomplishing this are illustrated and described herein.

One embodiment of this invention includes an elongated inlet vessel having a lower outlet end and an upper inlet end. The elongated inlet vessel can typically be in the form of a pipe, the diameter of which will be determined by the quantity of crude oil to be processed. While the pipe is an example of a readily available elongated vessel, the cross-section of the elongated vessel can be square, rectangular or other shape but for all practical purposes a pipe functions completely satisfactory and is readily available and inexpensive.

A second element making up the apparatus of this invention is a separation vessel that has an upper oil outlet, a lower water outlet and an intermediate inlet passageway. As with the inlet vessel, the separation vessel can, by example, be a length of pipe having a circular cross-section and the diameter of the separation vessel can typically be the same or substantially the same as the diameter of the inlet vessel. The separation vessel typically is elongated with respect to the diameter and may typically be about the same in length as the inlet vessel.

At least one electrode is positioned with the inlet vessel by which a mixture flowing therethrough is subjected to an electric field. The electrode may be, as an example, in the form of a coil conductor that receives the voltage applied through an insulator in the wall of the inlet vessel. The voltage may be applied between the electrode and the inlet vessel itself when the inlet vessel is a metallic conductor. The electrode may be insulated or in appropriate applications may be bare, that is in electrical contact with the mixture liquid flowing through the inlet.

The separator functions by providing short liquid flow paths. A mixture, after being subjected to an electric field within an inlet vessel is immediately passed to a separation vessel where passageways are provided for downward flow of separated water and upward flow of oil having a substantial portion of the water extracted therefrom.

The apparatus for separating water from a water-and-oil mixture may be arranged in series relationship whereby the percentage of water removed from the mixture is increased or may be arranged in a parallel relationship to adjust for varying quantities of crude oil being treated.

Another embodiment of this invention includes a first and a second elongated separator vessel both oriented on an incline and connected to one another so that the oil predominant flow exiting the outlet of the first vessel enters the inlet of the second vessel, where it is once again exposed to an electric field. Substantially dry oil then exits the second vessel. The water-and-oil mixture preferably enters the first vessel below the electrode but above the water level control in the lower end or water collection portion of the vessel. At least one of the separator vessels includes a plurality of baffles arranged parallel one another in the water collection portion of the vessel. The baffles may be horizontal, vertical, or, preferably, angled.

The first vessel may be arranged so that it is at the same elevation as that of the second vessel or at a different elevation. The inlet of the first or second vessel may be located below the electrode and above the water level control or it may be located at its upper end, thereby making the vessel a down flow vessel. A pretreatment or degasser unit may be connected to the inlet of the first elongated separator vessel.

The first vessel can run a bare electrode in circuit relationship to an AC voltage source at a lower potential. The ability to use a bare electrode is one advantage of the first vessel being an upflow vessel, the flow being pre-treated in the AC field. The moderate water fraction of the mixture exiting the first vessel and entering the second vessel, which can be an upflow or downflow vessel, allows for the use of an insulated electrode which may be in circuit relationship to a DC voltage source at a higher potential. The voltage source may include reactance. The second vessel could also use a bare electrode when configured as an upflow vessel

A method of separating water from the water-and-oil mixture includes the steps of:

(a) flowing the water-and-oil mixture into an inlet of a first elongated separator vessel, the first elongated separator vessel being oriented on an incline and having an outlet and an electrode located toward its upper end;

(b) passing the mixture through an electric field of the first elongated separator vessel whereby water in the water-and-oil mixture coalesces and a first water predominant fluid flows downward;

(c) flowing a portion of the first oil predominant fluid out of the outlet of the first elongated separator vessel and into an inlet of a second elongated separator vessel, the second elongated separator vessel being oriented on an incline and having an electrode located toward its upper end;

(d) passing the portion of the first oil predominant fluid through an electric field of the second elongated separator vessel whereby water in the oil predominant fluid coalesces and a second water predominant fluid flows downward.

The inlet of each separator vessel is preferably arranged relative to the electrode of the vessel to provide for a desired direction of flow, either an up flow or a down flow, for the passing steps (b) and (d). A portion of the first oil predominant fluid flowing out of the outlet of the first elongated separator vessel and into the inlet of a second or third elongated separator vessel may be a wet oil or a medium-wet oil portion. A second portion of the first oil predominant fluid may also be passed through an outlet and along a path which bypasses the second (or other subsequent) elongated separator vessels.

A better understanding of the invention will be obtained from the following detailed description of the preferred embodiments taken in conjunction with the drawings and the attached claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention will now be described in further detail. Other features, aspects, and advantages of the present invention will become better understood with regard to the following detailed description, appended claims, and accompanying drawings (which are not to scale) where:

FIG. **1** is an elevational view of a basic system for practicing the essence of the invention.

FIG. **2** is an alternate view of a basic system of the invention herein. FIG. **2** shows a tubular inlet vessel having an electrode therein by which a mixture is subjected to an electrostatic field and divergent water collection and oil collection portions in communication with oil treatment process and water treatment process vessels.

FIG. **3** is another alternate embodiment of the basic concept of the invention wherein the separation vessel is vertical with an upper product outlet and a lower water outlet.

FIG. **4** is an elevational view of an embodiment of the invention showing how basic systems used to practice the invention may be placed in series to achieve greater completeness of separation of water from the mixture. Further, FIG. **4** illustrates an inlet manifold and an outlet manifold that can be used so that the system extending between the manifold may be repeated in parallel to thereby adapt the system for increase volume applications.

FIG. **5** shows a desalter embodiment of the invention wherein a separation system is used in an application for extraction of salt from a mixture.

FIG. **6** shows another desalter system and illustrates how two of the basic separation systems of the invention may be employed in a network to provide more thorough water separation and salt removal.

FIG. **7** is a diagrammatic view showing how the basic arrangement of FIG. **2** may be repeated multiple times as necessary depending upon the level of dehydration required of the system. As an example, FIG. **4** illustrates two basic systems in sequence whereas FIG. **7** shows diagrammatically three basic systems in sequence.

FIG. **8** illustrates another embodiment of the invention wherein the basic separation system of the invention follows an inlet structure particularly useful in extracting gas from the inlet mixture and wherein two basic separation systems, the first like FIG. **2** and the second like FIG. **1**, are employed in series.

FIG. **9** illustrates another embodiment of the invention wherein the separation vessel is oriented at about 22.5° relative to horizontal.

FIGS. **10**, **11** and **12** provide cross-sectional views of alternate embodiments of the electrode. FIG. **10** illustrates a rod-type electrode configuration. FIG. **11** illustrates a coil-type electrode configuration. FIG. **12** illustrates a plate-type electrode configuration.

FIG. **13** is an alternate embodiment of the basic system for practicing the invention as first disclosed in FIG. **1**. This embodiment employs a horizontal transition section between the inlet vessel and the oil collection portion to reduce turbulence where the flow of separated water diverges from the flow of separated oil.

FIG. **14** is an alternate embodiment of a system for separating water from a water-and-oil mixture. Two up flow stages are arranged one above the other, each having the wet oil inlet located below the electrode.

FIGS. **15** to **15**B illustrate another alternate embodiment in which two up flow stages are arranged next to (or horizontal with) one another. Similar to the system of FIG. **14**, the wet oil inlet to each stage is located below the electrode.

FIG. **16** illustrates the system of FIG. **14** equipped with an optional degasser/pretreatment unit connected to the inlet of the first up flow stage.

FIG. **17** is a partial cross-section view of the water leg portion of each stage of FIG. **15** illustrating a plurality of baffles designed to improve water quality.

FIG. **18** illustrates the system of FIG. **15** equipped with an optional degasser/pretreatment unit connected to the inlet of the first up flow stage.

FIGS. **19** to **21** provide cross-sectional views of various baffle arrangements that may be provided in the water leg portion of the up flow stages of FIGS. **14** and **15**.

FIG. **22** is yet another alternate embodiment of a system for separating water from a water-and-oil mixture. The first stage is an up flow stage. The second stage is a down flow stage.

FIG. **23** is a view of the embodiment illustrated in FIG. **22** and taken along section line **23**-**23** of FIG. **22**.

FIG. **24**A is another alternate embodiment of a system for separating water from a water-and-oil mixture. Two down flow stages are preceded by degasser/pretreatment unit connected to the inlet of the first down flow stage.

FIG. **24**B is an alternate embodiment of the system of FIG. **24**A. Because of the relatively low pressure drop experienced across the stages, the separator vessels are plumbed to a single header and controlled with a single level control.

FIG. **25** is a schematic illustrating yet another alternate embodiment of a system made according to this invention for separating water from a water-and-oil mixture. An additional outlet is provided to the first stage which allows oil that is dry enough to meet a user's requirements to bypass the second stage.

FIG. **26** is a schematic illustrating another alternate embodiment in which an additional outlet is provided at the first and second stages to allow dry oil to bypass a subsequent stage.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

It is to be understood that the invention that is now to be described is not limited in its application to the details of the construction and arrangement of the parts illustrated in the accompanying drawings. The invention is capable of other embodiments and of being practiced or carried out in a variety of ways. The phraseology and terminology employed herein are for purposes of description and not limitation.

Elements shown by the drawings are identified by the following numbers:

10	Inlet vessel
12	Lower outlet end
14	Upper inlet end
16	Electrode
18	Separation vessel

-continued

20	Upper oil outlet end
22	Lower water outlet end
24	Inlet passageway
26	Inlet flange fitting
28	Outlet flange fitting
30	Pipe outlet fitting
32	Inlet longitudinal axis
34	Separation vessel longitudinal axis
36	Water collection portion
38	Water level
40	Water level control
42	Oil collection portion
44	Voltage source
46	Conductor
48	Conductor
50	Insulator
52	Water inlet
54	Water treatment process vessel
56	Oil outlet
58	Oil treatment process vessel
60	Second electrode
62	Inlet manifold
64	First separation system
66	Second separation system
68	Outlet manifold
70	Gas outlet
72	Piping
74	First separation system
76	Second separation system
78	Third separation system
80	T-fitting
82	Wash water inlet
84	Outlet
86	Mixing valve
88	Inlet
90	Desalter vessel
92	Water outlet
94	Oil outlet
96	Inlet
98	Preliminary separator
100	Gas outlet
102	Valve
104	3 phase voltage
106	Rectifier
108	DC Bus
110	Modulator
112	Conductors
114	Chopper
116	Primary
118	Transformer
120	Secondary
122	Ground
124	Conductor
124	Horizontal transition vessel
128	Tee fitting
130	First separation system/vessel
132	Second separation system/vessel
134	Baffle
136	Degassifier or pretreatment unit
138	Water collection portion
140	Third separation system/vessel
142	Dry oil path
144	Medium oil path

The basic concept of the invention is illustrated in its simplest embodiment in FIG. **1**. Basically the invention includes an elongated inlet vessel **10** having a lower outlet end **12** and an upper inlet end **14**. Positioned within inlet vessel **10** is an electrode **16** that provides an electrostatic field through which inlet liquid, identified in FIG. **1** as "feed", flows. In FIG. **1** electrode **16**, shown in dotted outline, is positioned within vessel **10** in which the vessel **10** is of conductive material, that is metal, so that the electrostatic field is established between electrode **16** and the wall of vessel **10**.

Inlet vessel **10** is elongated, that is, it has a length measured from the upper inlet end **14** to the lower outlet end **12** that is a multiple of the largest vessel cross-sectional dimension. In the illustrated arrangement of FIG. **1** the inlet vessel **10** is in the form of a pipe, that is, a vessel that, in cross-section, is round. The length of vessel **10** should preferably be about twice the vessel diameter, however the precise length is not a critical essence of the invention except that it is important that the vessel **10** be elongated so that fluid flowing therethrough is exposed for a minimum length of time to the electrostatic field established by electrode **16**.

A second basic element of the apparatus of FIG. **1** is a separation vessel **18**. Vessel **18** has an upper oil outlet end **20** and a lower water outlet end **22**. Further, separation vessel **18** has an intermediate inlet passageway **24** that communicates with the inlet vessel lower outlet end **12**.

As the invention is illustrated in FIG. **1**, an inlet flange fitting **26** is secured to the upper inlet end of inlet vessel **10** and a similar outlet flange fitting **28** is secured to the upper oil outlet end **20** of separation vessel **18**. Flange fittings **26** and **28** provide convenient devices for connecting the system of FIG. **1** to piping but are not otherwise involved in the performance of the system. In like manner, the lower water outlet end **22** of separation vessel **18** is provided with a pipe fitting **30** by which water separated by the system may be carried away for disposal or further treatment.

In the embodiment of the invention as revealed in FIG. **1**, a mixture of oil and water, designated as "feed" enters the system by way of inlet flange fitting **26** where it passes into inlet vessel **10**. The mixture flows through the elongated inlet vessel that is preferably downwardly sloped as indicated. Sloping the inlet vessel helps allow a high liquid flux past the electrodes. Within the inlet vessel the mixture is exposed to an electrostatic field. If electrode **16** within the inlet vessel is covered with insulation then electricity is not directly conducted from the electrode **16** to the mixture but instead only an electrostatic field is maintained within vessel **10** to which the mixture is exposed. By the use of an insulated electrode **16** the voltage between the electrode and the wall of vessel **10** can be significant so that an electrostatic field is applied to the inlet mixture. The electrostatic field causes water droplets within the mixture to rapidly coalesce. The mixture, with a significant portion of the water therein coalesced into large droplets immediately passes directly into separator vessel **18** that preferably is at an angle perpendicular to the longitudinal axis of inlet vessel **10**. In FIG. **1** the longitudinal axis of inlet vessel **10** is indicated by the numeral **32** while the longitudinal axis of separation vessel **18** is indicated by the numeral **34**.

The mixture having been subjected to an electrostatic field and therefore having passed through an environment in which the water is rapidly coalesced enters perpendicularly into separation vessel **18**. Within separation vessel **18** the inwardly flowing mixture is offered an immediate opportunity to separate into heavier and lighter components. The heavier component separates from the mixture and flows downwardly within the sloped separation vessel **18** into a water collection portion **36** which is the portion of vessel **18** below inlet passageway **24**. Water within water collection portion **36** is maintained at a selected level **38** by means of a water level control **40**. The water level control **40** is illustrated diagrammatically since such devices are frequently and customarily used in oil/water separation and are well known to any practitioner in the art. A typical water level control system is illustrated in and will subsequently be described with reference to FIG. **8**. Basically, the water level control **40** operates a valve (not seen) connected to the pipe fitting **30** to drain water as it accumulates within the vessel lower portion **36** so that the level **38** stays at a pre-selected height within water collection portion **36**.

The mixture flowing out of inlet vessel **10** through lower outlet end **12** separates and the lighter component is carried upwardly into an oil collection portion **42** of separation vessel **18**. The oil component of the feed mixture having at least a substantial portion of the water extracted therefrom flows through upper oil outlet end **20** of inlet vessel **10** and through outlet flange fitting **28** for transportation to a pipeline where it may be moved to a refinery, or is conveyed to a facility for storage or further processing.

The system for separating water from a water-in-oil mixture of FIG. **1** is of ultimate simplicity compared to most oil/water separation equipment in use today and yet is arranged to provide improved performance. Specifically, a unique aspect of the separation system of FIG. **1** is that an oil/water mixture is subjected to an electrostatic field and immediately thereafter passes for separation with the water component flowing in one direction and the oil component flowing in an opposite direction. Further, the sloped arrangements of inlet vessel **10** and separation vessel **18** provide immediate gravity-assisted separation of a water-in-oil mixture after exposure to an electrostatic field. The apparatus of FIG. **1** provides the most immediate and effective separation of oil and water in the simplest possible flow arrangement as compared with other known systems.

In FIG. **1** the rudiments of the method of applying an electrostatic field to the mixture within inlet vessel **10** is illustrated. A voltage source **44** provides a voltage output between conductors **46** and **48**. Conductor **48** is secured to the sidewall of inlet vessel **10** while conductor **46** is fed through an insulator **50** that extends through the sidewall of vessel **10** to electrode **16**. Voltage across conductors **46** and **48** may be an AC voltage, a DC voltage, a pulsing DC voltage or a dual frequency voltage. The particular voltage applied to create an electrostatic field within the inlet vessel is not a critical element of the invention since much work has been done to define the advantages and disadvantages of various voltage systems used to augment coalescence of water in a water-in-oil mixture. As an example, U.S. Pat. No. 6,860,979 teaches a dual frequency electrostatic coalescence system that may be applied to the apparatus of FIG. **1**. Such a dual frequency system is better illustrated and will be discussed with reference to FIG. **6**.

The basic system of the invention illustrated in FIG. **1** is susceptible of a variety of modifications. FIG. **2** shows one example of a modification of FIG. **1** in which the inlet vessel **10**, lower outlet **12**, upper inlet **14**, and electrode **16** all have the same element number and same purpose as described with reference to FIG. **1**.

Inlet vessel lower end **12** is connected in a straight line with a water collection portion **36**A that has a water level control **40** to maintain a water level **38** as described with reference to FIG. **1**. The lower water outlet end **22** of the water collection portion in FIG. **2** connects to the inlet **52** of a water treatment process vessel **54** that is illustrative of any system that provides for treating and/or disposing of water extracted from the inlet mixture. The water treatment process **54** may include simply a disposal of the water extracted from the inlet water/oil mixture or it may represent further treatment to remove any residuary oil carried over from the inlet mixture, such as a hydrocyclone, a centrifugal force separator, a gravity separator, a corrugated plate separator, a flotation cell or a filter.

In the arrangement of FIG. **2** the inlet mixture flowing into the system through inlet flange **26** is subjected to an electric field provided by electrode **16** that functions to cause the water portion of the inlet mixture to coalesce. The coalesced water continues to flow downwardly into water collection portion **36**A. Oil that separates out of the mixture and therefore that remains above the water level **38** turns upwardly and flows into oil collection portion **42**A. Separated oil flows out of the collection portion **42**A through upper oil outlet end **20** and through an oil outlet **56** into an oil treatment process area indicated by vessel **58**. Oil treatment process vessel **58** is emblematic of any system for further handling, transports, treatment or storage of oil separated by the system of FIG. **2**. Typically the oil treatment process **58** can be a storage facility where crude oil having a substantial portion of the water extracted therefrom is stored prior to being transported for further use, such as to a refinery for processing.

Comparing FIG. **2** with FIG. **1** shows two distinct differences. First, FIG. **2** illustrates water treatment process vessel **54** and oil treatment vessel **58** as emblematic of further treatment of separated oil and water exiting from the systems. Second, FIG. **2** compared to FIG. **1** shows a different geometrical arrangement of the flow paths of oil and water that have been separated from an inlet oil-in-water mixture. In both FIG. **1** and FIG. **2** separated oil changes directions and moves upwardly at an angle relative to the flow path of the inlet mixture. However, in FIG. **2**, compared to FIG. **1**, separated water continues in the same flow path of the inlet vessel. Irrespective of these differences the basic function of the systems of FIGS. **1** and **2** is the same. That is, an inlet mixture of oil-in-water flows in a downward direction through an elongated inlet vessel during which time it is subjected to an electrostatic field and a separation vessel has an inlet passageway in communication with the inlet vessel lower outlet end. FIG. **2** shows an arrangement wherein an inlet mixture of oil-in-water is subject to an electrostatic field and immediately thereafter separate passageways are provided by which the separated water and oil flows in different directions.

FIG. **3** shows another alternate embodiment of the system of this invention. In FIG. **3** inlet vessel **10** is elongated and downwardly sloped, the same as shown in FIGS. **1** and **2**. However, in FIG. **3** the oil collection portion **42**B is vertically upward. The longitudinal axis **32** intersects the separation vessel longitudinal axis **34** at an angle of about 45°. In FIG. **3** the mixture after having passed through the electrostatic field established by electrode **16** within inlet vessel **10** turns and enters horizontally into oil collection portion **42**B that is in vertical alignment with water collection portion **36**B. Separated water from the mixture coalesced by action of the electrode **16** immediately turns downwardly into the water collection portion **36**B and the separated lighter oil component immediately turns upwardly into oil collection portion **42**B and flows out upper oil outlet **20**. Thus as with FIGS. **1** and **2**, the inlet mixture is subjected to an electrostatic field and immediately thereafter the flow from the inlet mixture enters a divergent path in which separated water can flow in a direction divergent from the separated oil. In the case of FIG. **3** the separated water component immediately diverges into a downward path into water collection portion **36**B while the separated oil component flows in the opposite direction, that is, upwardly into oil collection portion **42**. Thus, FIG. **3** provides the same unique concept as FIGS. **1** and **2**, that is, a mixture inlet through an elongated vessel in which the mixture is subject to an electrostatic field followed immediately by divergent flow pathways for the separated water and oil components.

FIG. **9** shows another alternate embodiment of the system of this invention. The inlet vessel **10**, lower outlet **12**, upper inlet **14**, and electrode **16** all have the same element number and same purpose as described with reference to FIGS. **1**, **2** and **3**. Inlet vessel **10** is elongated and downwardly sloped but with flange fitting **26** oriented to receive a vertical feed. Both the water collection portion **36**C and the oil collection portion

42C of the separator vessel **18** are aligned along the separation vessel longitudinal axis **34** and oriented at an angle of about 22.5° relative to the horizontal. The inlet vessel longitudinal axis **32** is perpendicular to the separation vessel longitudinal axis **34**. The mixture separates, after having passed through the electrostatic field established by electrode **16** within inlet vessel **10**, and the separated water turns angularly downward into the water collection portion **36**C and the separated lighter oil component turns angularly upward into the oil collection portion **42**C and flows out upper oil outlet **20**. The outlet flange fitting **28** is oriented such that it can connect to a vertically oriented oil treatment process area. Thus as with FIGS. **1**, **2** and **3** the inlet mixture is subjected to an electrostatic field and immediately thereafter the flow from the inlet mixture enters a divergent path in which separated water can flow in a direction divergent from the separated oil. As suggested by FIGS. **1**, **2**, **3** and **9**, the angle of inlet vessel **10** can range from 0° to 45° relative to vertical and the angle of the separation vessel **18** can range from 0° to 45° relative to horizontal.

FIGS. **1**, **2**, **3** and **9** each make use of plural electrostatic fields. In each of FIGS. **1**, **2**, **3** and **9**, in addition to electrode **16** positioned within the inlet vessel **10**, a second electrode **60** is positioned within the oil collection portion **42**, that is, there is a second electrode **60** within oil collection portion **42** of FIG. **1**, within oil collection **42**A of FIG. **2**, within oil collection **42**B of FIG. **3**, and within oil collection **42**C of FIG. **9**. Each of the second electrodes provide electrostatic fields in the same way as the primary electrode **16** in each embodiment and serves to further aid in the coalescence of any water remaining in the separated oil after first separation has taken place. The secondary electrodes **60** may be insulated or if the percentage of water remaining in the mixture within the oil collection portion of the apparatus has diminished sufficiently then the secondary electrodes **60** may be bare electrodes operating at lower voltages.

FIG. **4** shows how the basic separation system of this invention may be used in series to more completely separate water from a water-in-oil mixture. FIG. **4** shows an inlet manifold **62** by which a water-in-oil mixture is fed into a first separation system generally indicated by the numeral **64** that has the components with the same numerical identification as FIG. **1**. Outlet flange **28** of first separation system **64** connects to an inlet flange **26**A of a second separation system **66**. The outlet flange **28**A of separation system **66** communicates with an outlet manifold **68** whereby the oil component of the mixture that flows in inlet manifold **62** is collected. Thus the first separation system **64** and second separation system **66** each function identically as has been described with reference to FIG. **1** in that each has an inlet vessel **10**, a water collection portion **36** and an oil collection portion **42**. Each inlet vessel has an electrode **16** and each water collection portion **36** has a pipe fitting by which water separated from the feed mixture is conveyed away from the separation system. Further, there is a second electrode **60** in both separation systems **64** and **66**.

One difference in FIG. **4** compared to FIG. **1** is that a gas outlet is illustrated in communication with each of the inlet vessels **10** and **10**A. Each gas outlet **70** and **70**A is connected by piping **72** by which gas separated from the system can be carried away, such as to a gas collection facility, a flare or so forth.

FIG. **7** is a diagrammatic illustration of how the separation system of FIG. **2** can be connected in series. FIG. **7** diagrammatically shows a separation system **74** that functions as illustrated and described with reference to FIG. **2** and identical separation systems **76** and **78** connected in series. This is illustrative of the fact that separation systems as described herein may be connected in series with as many as necessary substantially identical separation systems connected in series to achieve the level of separation required.

Referring back to FIG. **4**, this view suggests that the separation systems of this invention can easily be placed in parallel. FIG. **4** shows two separation systems **64** and **66** extending in series from an inlet manifold **62** to an outlet manifold **68**. It is easy to see that any number of the systems illustrated in FIG. **4** can be placed side-by-side, in parallel, each extending from inlet manifold **62** to outlet manifold **68**. In like manner the system of FIG. **7** could easily be placed in parallel with as many separation systems as required according to the volume of a water-in-oil mixture to be treated.

FIG. **5** illustrates how a separation system of this invention may be employed in a desalter system. In FIG. **5** a first separation system **64** as is described with reference to FIG. **1** functions to provide separated oil at outlet flange fitting **28** that is connected to a T-fitting **80** having a wash water inlet **82**. The separated oil flowing from outlet flange **28** mixes with wash water in T-fitting **80**, and the mixture passes out of the T-fitting through outlet **84**, through a mixing valve **86** and through an inlet **88** pipe to a desalter vessel **90**. In vessel **90** a quiet zone is provided allowing the oil and water to separate. The water introduced through wash water inlet **82** absorbs salt content in the oil discharged from first separator system **64**. From desalter vessel **90** water passes out through outlet **92** and oil having substantially all the water and substantially all the salt removed therefrom flows out through oil outlet **94**.

The basic concepts of the desalter of FIG. **5** are known, that is the step of using wash water to mix with oil having salt therein is known and is not the essence of the invention. The significance of FIG. **5** is that it shows how a separation system **64** of this invention can be used in a desalter to improve the efficiency and effectiveness of the desalter system.

FIG. **6** shows a further illustration of how the separation systems of this invention may be used in a desalting arrangement. A first separation system **64**, as illustrated and described with reference to FIG. **1**, provides separated oil through outlet flange **24** into a T-fitting **80** having a water inlet **82** as described in FIG. **5**. The mixture passes through mixing valve **86** as described and into another inlet flange fitting **26** of a second separation system **66** that again is the same as the basic separation system of FIG. **1**. The separated oil flowing through outlet fitting **28**A enters a desalter vessel **90** where the water and oil components of the mixture separate by gravitation with the water having dissolved salt therein and relatively salt-free oil passing upwardly and out of the desalter through oil outlet **94**.

FIG. **6** shows more details of circuitry by which a voltage may be applied to an electrode within a separation system to which reference will be made subsequently.

FIG. **8** shows one way in which separation systems of this invention can be added in series. In FIG. **8** an oil/water mixture enters through an inlet **96** into a preliminary separator **98** that is in the form of a vertical vessel having a gas outlet **100** at the top. Liquid passes downwardly in preliminary separator **98** with easily separated water component settling to the bottom into a water level **38** maintained by a water level control **40**. The control **40** operates a water discharge valve **102** so that the level **38** is maintained within vessel **98**. A pipe outlet fitting **30** provides for conveying water away from preliminary separator **98**. The mixture having gas and easily separated water removed therefrom flows into a first separator system **74** like that described in FIG. **2**.

As water is separated from the oil content of the mixture within separation system **74** it flows downwardly into water collection portion **36**A and ultimately is drained out pipe outlet fitting **30**. Oil from the mixture moves upwardly through oil collection portion **42** where it is again exposed to an electrostatic field by second electrode **60**. The separated oil moves through oil outlet **56** and into a second separation system **64** and through downwardly inclined inlet vessel **10** having an electrode **16** therein. In the separation system **64** the mixture is treated as has been described with reference to FIG. **1**, that is, in a basic separation system of this invention. From inlet vessel **10**, the mixture, after being subjected to the electrostatic field provided by electrode **16**, flows into separation vessel **18**, the water being channeled downwardly into the water collection portion **36** where it mixes with water draining out of water collection portions **36**A of separation system **74** and passes out of the system through a pipe outlet **30**. The oil passing out of inlet vessel **10** is channeled upwardly through oil collection portion **42** and out through outlet flange fitting **28**, all in the manner as described with reference to FIG. **1**.

FIG. **8** is an illustration of how the unique separation system of this invention lends itself to a variety of combinations, all achieved with the basic concepts as revealed in FIG. **1**. In the system of FIG. **8** the mixture is subjected to electrostatic field provided by four (4) electrodes. To achieve highly effective separation of water from the oil contained in the mixture, the strength of the electrostatic field of successive electrodes can be increased since each is in a portion of the system wherein the water content of the mixture has been reduced. As an example, while electrodes **16** and **60** of separation system **74** may be insulated, electrodes **16** and **60** of separation system **64** may be uninsulated, that is bare. Additionally, as shown by FIGS. **10**, **11** and **12**, different electrode configurations may be used for electrodes **16** and **60** in order to achieve the desired electrostatic field. For example, in FIG. **10** electrodes **16**A are in the form of parallel plates. In FIG. **11** the electrodes **16**B are in the form of concentric cylindrical members **16**B, while in FIG. **12** a coaxial electrode **16**C is in the shape of a rod surrounded by a concentric cylindrical member **16**D. Second electrode **60** may have any of the cross-sectional arrangements shown in FIGS. **10**, **11** and **12**.

As mentioned with reference to FIG. **1**, each of the electrodes employed in the separation systems described herein is supplied by a voltage potential which may be an AC voltage, a DC voltage, a rectified AC voltage or an AC voltage having selected frequencies and wave forms. An effective voltage format for use with the electrostatic separator systems of this invention is a dual frequency voltage as described in detail in U.S. Pat. No. 6,860,979 entitled "Dual Frequency Electrostatic Coalescence." This patent issued on May 1, 2005, and is incorporated herein by reference. FIG. **6** shows a basic circuit revealed in this patent by which a dual frequency voltage is applied to electrode **16** of separation system **64**. In this dual frequency circuit a three-phase voltage source **104** is applied to a rectifier **106** to produce a voltage on a DC bus **108**. Voltage from DC bus **108** supplies a modulator **110** that, by signals fed on conductors **112**, controls a chopper **114** that provides an AC voltage of selectable frequency to the primary **116** of a transformer **118**. The secondary **120** of transformer **118** applies voltage between ground **122** and a conductor **124** that supply voltage passing through insulator **50** to electrode **16**. The circuit of FIG. **6** provides a method of augmenting the separation of the oil and water components of a mixture flowing through inlet vessel **10** by providing an AC voltage source of a readily selectable frequency F**1** that is modulated in intensity at a selected frequency F**2**.

FIG. **13** illustrates an alternate embodiment of the invention as compared to the basic embodiment of FIG. **1**. In FIG. **13** a horizontal transition vessel **126**, typically in the form, as illustrated, of a length of pipe, interconnects oil collection vessel **42** with inlet vessel **10**. A tee fitting **128**, extends from the bottom of horizontal transition vessel **126** and connects to the inlet of water collection vessel **36**. Thus water separating in inlet vessel **10** and oil collection vessel **42** settles to the bottom of horizontal transition vessel **126** and drains out through tee fitting **128** into water collection vessel **36** while encountering reduced turbulence.

In the drawings the basic configurations of the separator of this invention is illustrated in FIGS. **1**, **2**, **3**, **9** and **13**. Different systems by which this separator system can be applied are illustrated in FIGS. **4**, **5**, **6**, **7** and **8**. FIGS. **5** and **6** illustrate specifically how the separator system herein can be employed in a desalting system in which wash water is utilized. It is important to emphasize that the illustrations of how the separator system of this invention can be modified into various configurations, as exemplified in FIGS. **4** through **8**, are examples only and by no means are illustrated as the only arrangements by which the separator system can be employed.

Referring now to FIG. **14**, a first separation vessel **130** and a second separation vessel **132** are arranged one above the other, each vessel **130** being an upflow leg or stage that has the wet oil inlet **14** located below the electrode **16** but above the water level control **40** (and therefore above the water level **38**). The orientation of the vessels **130**, **132** may vary from vertical to horizontal (see FIGS. **15** to **15**B) relative to one another. A vertical orientation has logistical advantages and a horizontal orientation has fluid flow advantages. Varying between the two orientations blends the advantages of both orientations.

As the wet oil enters through inlet **14** of the first vessel **130** below the electrode **16**, the wet oil is substantially immediately affected by the electric field. The largest water droplets coalesce and flow downward into the water collection portion **26** before the wet oil encounters the electrode **16**. The angle of the vessel **130** relative to horizontal (see e.g., FIG. **15**) allows the expedited countercurrent removal of the coalesced water to the water collection portion **26**. As the drier oil flows upward to the oil collection portion **42** of the vessel **130**, smaller water droplets coalesce and separate into the countercurrent flow. The drier oil passes from the outlet **20** of the first vessel **130** and enters the inlet **14** of second vessel **132** below the electrode **16**, where the above separation process is repeated. Each vessel **130**, **132** is equipped with a gas outlet **70** by which gas separated from the system can be carried away, such as to a gas collection facility, a flare or so forth.

A plurality of baffles **134** that are arranged parallel to one another may be provided in the water collection portion **26** of each vessel **130**, **132**. The baffles **134**, which are preferably oriented parallel to the axis of the vessel **130**, **132** may be vertical, horizontal, or angled baffles (see FIGS. **19** to **21**). A vertical baffle decreases the Reynolds Number and, therefore, system turbulence. A horizontal baffle decreases the Reynolds Number and settling distance. However, a horizontal configuration increases the number of surfaces on which sand may accumulate. Additionally, the separated oil droplets must cross the water flow in order to travel upward and recombine with the continuous oil phase. An angled baffle—that is, a baffle oriented between 0 and 90 degrees—has the potential to combine the advantages of vertical and horizontal baffles, providing shorter settling distances and an increased angle of repose for the sand. The separated oil droplets cross the water flow at the wall where flow velocity is a minimum.

As illustrated in FIGS. **16**, **18**, and **24**A & B a degasser or pretreatment unit **136** may be connected to the inlet **14** of the first separator vessel **130**. Pretreatment prevents excessive gas from entering into vessel **130** (and **132**) and reduces the inlet water volume by initiating water removal. In a preferred embodiment, the pretreatment unit **136** is a PORTA-TEST WHIRLYSCRUB® V™ vertical centrifugal separator (Cameron Corp. Process Systems, formerly National Tank Company Corp., Houston, Tex.) or CONSEPT ICD™ centrifugal separator (also Cameron Corp. Process Systems, formerly National Tank Company Corp., Houston, Tex.). The tangential inlet on these particular centrifugal separators promotes free-gas removal and initiates free-water coalescence by creating a high-g environment. As illustrated in FIGS. **24**A & B, pretreatment unit **136** may include a water collection portion **138**.

Experiments by the inventors on various configurations of a compact electrostatic separator made according to this invention have provided insights into what works best. Different performance characteristics depend on whether the oil-water flow is upward or downward. For example, the oil-water flow in the arrangement of FIGS. **24**A & B is a downward flow in each of the separator vessels, **130**, **132** (with the pretreatment unit **136** and vessels **130**, **132** being connected to a single header in FIG. **24**B and controlled by a single level control). With respect to inlet water fraction, for high water fractions (about 30-70% BS&W), up flow yields superior results whereas for moderate water fractions (about 5-10% BS&W) down flow performs better. With respect to outlet water fractions, the up flow configuration has a limit on the amount of water that can be removed. The drag of the upward flowing oil prevents small amounts of water from falling into the water collection portion **36** of the vessel **130**, **132**, and this configuration can dry oil only to moderate fractions. However, with moderate inlet water fractions, a down flow configuration can yield oil with a low (<1%) water fraction.

With respect to the electrostatic technique, AC is the only appropriate technique in up flow configurations given very wet oil inlet flows. Furthermore, the electrode **16** is preferably a bare electrode when the wet oil has a high water fraction. Because the flow coming into a down flow configuration is moderately wet, there is a possibility to use AC as well as dual polarity and dual frequency techniques to achieve very dry outlet oils. As discussed previously in connection with FIG. **6**, an effective voltage format for use with the electrostatic separator systems of this invention is a dual frequency voltage as described in detail in U.S. Pat. No. 6,860,979 entitled "Dual Frequency Electrostatic Coalescence" and incorporated herein by reference. The moderately wet inflow also provides an opportunity to use an insulated electrode **16**.

Referring now to FIGS. **22** and **23**, a compact electrostatic separator is illustrated that combines the most advantageous features of an up flow and a down flow configuration. Wet oil enters the inlet **14** of a first separator vessel **130**, which is in an up flow configuration, below the electrode **16** and above the water level control **40**. Because of the high water fraction of the wet oil, first stage electrode **16** is a bare electrode used in combination with AC technology. Electrode **16** causes water droplets to coalesce and fall out of the oil-water mixture into the water collection portion **36**. Because of the high density of the water relative to the oil and its low viscosity, most of the water can fall out of the mixture into the water collection portion **36**. However, at some point, the drag force of the upwardly moving oil-water mixture exceeds the remaining water's ability to move downward. With much of the water exiting the lower water outlet end **22** of the first vessel **130**, a moderately dry oil exits the upper oil outlet end **20** of vessel **130** and enters the inlet **14** to a second separator vessel **132**, which is in a down flow configuration.

The moderately dry oil enters the second vessel **132** about even with the electrode **60**. Second stage electrode **60** performs the same function as that of the first stage electrode **16**. Electrode **60** may be an insulated electrode and used in combination with AC or with dual polarity and dual frequency techniques. With the momentum of the water and the mixture being in the same direction, the drag on the oil-water mixture is reduced and much more of the remaining water can fall out into the water collection portion **36** of the second vessel **132**. This water exits at the lower water outlet end **22** and nearly dry oil exits from the upper oil outlet end **20**. Note that because upper oil outlet end **20** of the first vessel **130** and the inlet **14** of the second vessel **132** are both at the upper ends of the vessels **130**, **132**, this configuration occupies less space than the systems illustrated, for example, in FIGS. **14** and **15**.

Laboratory studies demonstrate that the addition for reactance to the transformer **118** (see FIG. **6**) is beneficial. From preliminary lab data, when the reactance is absorbing about 5 to 70% of the input voltage, it is performing two functions. First, it limits both the number and length of arcing short circuits. This tends to increase the applied voltage on the electrode **16** and produce more coalescence. Second, the voltage adjustments caused by the arc response induce a voltage modulation. This voltage modulation enhances the coalescence of water droplets of varying size, which leads to improved separation. The combination of these two properties improves the quality of both the oil and water (see Tables 1 and 2).

TABLE 1

Effect of Added Reactance on the Quality of Oil and Water.
2000 Volts 1st Electrode; 5000 Volts 2nd Electrode
~100° F. 2000 B/D psf, 32-34% H_2O

Amps 1st	Amps 2nd	Added Reactance MHY	% H_2O Dry Oil Out	Angle of Baffle	PPM Oil 1st Water Outlet	% Oil 2nd Water Outlet
1.4	0.4	0	5.6*	0	160	36*
1.4	0.4	0	5.6*	45	179	36*
1.4	0.4	0	5.6*	90	261	36*
0.5	0.4	35	5.2	45	58	1.7
0.5	0.4	47	5.6	45	123	2.7
0.5	0.4	59	5.5	45	120	2.3
0.6†	0.6	59	4.9	45	94	0.5

*Values averaged

†One sample only 3000 Volts and 7500 Volts

TABLE 2

Effect of Added Reactance and No Baffles in the Second Separator Vessel on the Quality of Oil and Water. ~100° F. 2000 B/D psf, 32-34% H_2O

Amps 1st	KVoltage In/Out	Amps 2nd	KVoltage In/Out	Added Reactance MHY	% H_2O Dry Oil Out	Angle of Baffle	PPM Oil 1st Water Outlet Baffled	PPM Oil 2nd Water Outlet Not Baffled
0.6	4.0/1.7	0.6	8.0/7.6	56	5	45	49	10K
0.6	4.0/1.7	0.9	9.1/8.2	56	4.6	45	57	5K
0.6	4.0/1.7	1.3	11.0/9.1	56	4.3	45	51	220

Referring now to FIGS. **25** and **26**, an additional oil outlet **20***a* is provided that routes oil dry enough to meet a user's requirements on a dry oil path **142** that bypasses the second separator vessel **132**. In FIG. **25**, wet oil (about 30-70% H_2O) enters inlet $\mathbf{14}_{(1)}$ of the first separator vessel **130** and dry oil (about <1% H_2O) exits at the top end of the vessel **130** through outlet **20***a*. The balance of the medium-wet or moderately dry oil (about 5-10% H_2O) exits outlet $\mathbf{20}_B$ and enters the inlet $\mathbf{14}_{(2)}$ of the second separator vessel **132**. Dry oil then exits the second vessel **132** through outlet $\mathbf{20}_D$ and along dry oil path **142**. Preferably, the flow through outlet $\mathbf{20}_A$ is controlled to ensure that any oil that exceeds the user's requirements is not routed through the outlet $\mathbf{20}_A$ (thereby bypassing the second vessel **132**). The same holds true for outlet $\mathbf{20}_D$.

In FIG. **26**, the first separator vessel **130**, which is an up flow vessel, includes two additional outlets $\mathbf{20}_A$ and $\mathbf{20}_B$. Preferably, outlet $\mathbf{20}_B$ is located in close proximity to the wet oil inlet **14**. As wet oil passes through inlet $\mathbf{14}_{(1)}$ and enters the first separator vessel **130**, a portion of the wet oil is diverted to outlet $\mathbf{20}_B$ and into inlet $\mathbf{14}_{(2)}$ of the second separator vessel **132**, which is also an up flow vessel. Dry oil that meets the user's requirements exits through additional outlet $\mathbf{20}_A$ located at the top end of vessel **130** and travels along path **142**.

The second separator vessel **132** converts the wet oil from the first vessel **130** to a medium-wet oil, which exits the second vessel **132** through outlet $\mathbf{20}_D$ and travels along medium-wet oil path **144** to the inlet $\mathbf{14}_{(3B)}$ of an additional or third separator vessel **140**. Vessel **240** is a down flow vessel substantially similar in structure to that of vessels **130**, **132** as illustrated in, for example, FIGS. **24**A & B. Medium- or moderately wet oil which passes through outlet $\mathbf{20}_C$ of the first vessel **130** also travels along medium-wet oil path **144** to the inlet $\mathbf{14}_{(3A)}$ of a third vessel **140**. Dry oil then exits through outlet $\mathbf{20}_E$ of the third vessel **140** and travels along dry oil path **142**.

While the invention has been described with a certain degree of particularity, it is manifest that many changes may be made in the details of construction and the arrangement of components without departing from the spirit and scope of this disclosure. It is understood that the invention is not limited to the embodiments set forth herein for purposes of exemplification, but is to be limited only by the scope of the attached claims, including the full range of equivalency to which each element thereof is entitled.

What is claimed is:

1. A method of separating water from a water-and-oil mixture, the method comprising the steps of:

(a) flowing a water-and-oil mixture into an inlet of a first elongated separator vessel, the first elongated separator vessel being oriented on an incline and having an electrode located toward its upper end;

(b) passing the water-and-oil mixture through an electric field of the first elongated separator vessel whereby water in the water-and-oil mixture coalesces and a first water predominant fluid flows downward;

(c) flowing a portion of a first oil predominant fluid out of an outlet of the first elongated separator vessel and into an inlet of a second elongated separator vessel, the second elongated separator vessel being oriented on an incline and having an electrode located toward its upper end;

(d) passing the portion of the first oil predominant fluid through an electric field of the second elongated separator vessel whereby water in the portion of the first oil predominant fluid coalesces and a second water predominant fluid flows downward; and

(e) allowing a second portion of the first oil predominant fluid to exit an outlet of the first elongated separator vessel and bypass the second elongated separator vessel.

2. A method according to claim **1** the inlet to the first elongated separator vessel and the second elongated separator vessel is located relative to the electrode to provide for a predetermined direction of flow of the water-and-oil mixture as the water-and-oil mixture enters the separator vessel, the direction of flow being a direction of flow selected from the group consisting of an upward direction of flow and a downward direction of flow.

3. A method according to claim **1**, the portion of the first oil predominant fluid flowing out of the outlet of the first elongated separator vessel and into the inlet of the second elongated separator vessel is a portion selected from the group consisting of a wet oil portion and a medium-wet oil portion.

4. A method according to claim **1** further comprising the step of flowing the water-and-oil mixture to a pre-separation unit prior to said step (a).

5. A method according to claim **1**, at least one of the first water predominant flow and the second water predominant flow passes through a plurality of baffles.

6. A method according to claim **1**, the electrode of the first and second elongated separator vessels is each in circuit relationship to a voltage source at a different potential than the other voltage source.

7. A method of separating water from a water-and-oil mixture, the method comprising the steps of:

(a) flowing a water-and-oil mixture into an inlet of a first elongated separator vessel, the first elongated separator vessel being oriented on an incline and having an electrode located toward its upper end;

(b) passing the water-and-oil mixture through an electric field of the first elongated separator vessel whereby water in the water-and-oil mixture coalesces and a first water predominant fluid flows downward;

(c) flowing a portion of a first oil predominant fluid out of an outlet of the first elongated separator vessel and into an inlet of a second elongated separator vessel, the second elongated separator vessel being oriented on an incline and having an electrode located toward its upper end;

(d) passing the portion of the first oil predominant fluid through an electric field of the second elongated separator vessel whereby water in the portion of the first oil predominant fluid coalesces and a second water predominant fluid flows downward; and

(e) after said step (a), allowing a portion of the water-and-oil mixture to substantially immediately exit an outlet of the first elongated separator vessel and flow into an inlet of an additional elongated separator vessel, the additional elongated separator vessel being oriented on an incline and having an electrode located toward its upper end; and

(f) passing the portion of the water-and-oil mixture through an electric field of the additional elongated separator vessel whereby water in the portion of the water-and-oil mixture coalesces and a third water predominant fluid flows downward.

8. A method according to claim **7**, the inlet to the additional elongated separator vessel is located relative to the electrode to provide for a predetermined direction of flow of the water-and-oil mixture as the water-and-oil mixture enters the additional elongated separator vessel, the direction of flow being a direction of flow selected from the group consisting of an upward direction of flow and a downward direction of flow.

9. A method according to claim **8** further comprising the step of:

(g) flowing a portion of a third oil predominant fluid out of an outlet of the additional elongated separator vessel and into an inlet of the second elongated separator vessel.

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